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NOTES ON COLORIMETRIC TESTS FOR CITRUS SPECIES

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RESEARCH workers in citriculture often find it necessary to determine definitely the species of a stock of a budded tree or the species of an unknown citrus fruit. Where the stock has shoots coming from it or from exposed root portions, positive identification is sometimes possible from the morphology of the leaves on such a shoot. Also, with such a stock as trifoliata, the characteristic nature of the union is a distinct identifying feature. With unknown citrus types, however, be they variants or "natural hybrids", identification based on morphological characters is often far from satisfactory.

The need for a more general and more certain means of identification of citrus species has long been felt, and Hendricksen (4) published the first step towards providing this. However, Hendricksen himself admitted that the method of treating the aqueous extract of ground, fresh roots with ferric chloride was reliable for only rough lemon, and since the method also had the disadvantage of having to work with fresh material, it has not been much used.

Halma and Haas (2) have presented the results of extensive work on the use of chemical reagents for differentiating between aqueous extracts of ground, dried bark of four citrus species: sweet orange (*Citrus sinensis* Osbeck), sour orange (*C. Aurantium* L.), grapefruit (*C. maxima* Merrill), and rough lemon (*C. limonia* Osbeck). Their recommended method makes use of the ALMEN test for carbolic and salicylic acids as given by Cohn (1). Halma (3) has since published a modification of the ALMEN test which requires a smaller amount of bark material and gives greater colour differences in a shorter period.

He describes it thus: "Enough bark is lifted from the rootstock trunk to make at least 0.5 grams when dried at about 70° C. After drying it is ground fine enough in a mortar to pass through a 40-mesh sieve. 0.5 grams of this powder is placed in a beaker and 20 cc. of distilled water is added. After several minutes the contents of the beaker are transferred to filter paper and the residue washed with 10 cc. of water. The 0.5 grams of powder are therefore leached with 30 cc. of water, and 5 cc. of the filtrate are made alkaline with 2 drops of potassium hydroxide prior to adding 10 drops of a saturated solution of copper sulphate. This is followed by 10 drops of mercury reagent

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which is made up as follows:—160 grams of re-distilled mercury are dissolved in 160 grams of red fuming nitric acid (specific gravity 1.60) and this is finally diluted with 320 cc. of distilled water. 10 drops of this reagent are added to the contents of the test tube and boiled. The resulting colour of the solution identifies the variety."

The citrus species tested by Halma and Haas are, in the order of their importance, the rootstocks used in the commercial propagation of citrus trees in California. In Florida the sour orange, rough lemon and sweet orange are used as rootstocks, and trifoliata (*Poncirus trifoliata* Raf.) as a stock for Satsuma oranges. In Palestine and Brazil the lime (*C. aurantifolia* Swingle) is used to a great extent, while in South Africa the rough lemon is used exclusively at present as a stock for the production of all commercial citrus trees. Citrus rootstock investigations in all the mentioned countries are bringing to light the possibilities of other citrus species and citrus hybrids as rootstocks, particularly the suitability of different stocks for individual citrus species and for varieties of the same species; e.g. the Calamondin orange (*C. mitis* Blanco) for tangerines and mandarins in Florida, and the tangelo (an artificial grapefruit × tangerine hybrid) for the Washington Navel orange and other commercial varieties in different parts of California.

In such citrus growing areas as California and Florida, where intensive commercial production has been going on for many years, practically all the trees now growing are of well-known varieties, have been produced commercially, and are on one of the four commercial stocks. Consequently there are very few "wild" trees and seedlings of varying types still in existence. In South Africa there is still to be found an abundance of citrus species and varietal types growing on farms of the early settlers. Most of these are seedling sweet oranges, many trees are over 90 years old and one planting is known to be 130 years old. Fruit from such old seedlings is continually being submitted for identification, and difficulty is often experienced in identifying what are either very great morphological variants or "natural" hybrids of the known citrus species. Such fruits, which have been named "sweet rough lemon", "dwarf rough lemon", "naartjie-orange" hybrid, "dwarf orange", "cluster lemon", etc., have to be submitted to a reliable test before positive identification of the species is possible.

Since the apparent, absolute failure of the sour orange (bitter Seville) as a stock in South Africa (held to have been proven so some thirty years ago, although this, in the words of Dr. H. J. Webber, "seems like a physiological impossibility"), probably 99 per cent. of the budded trees in the country were put on rough lemon stock. However, scattered around are old budded trees on stock other than rough lemon, being on sweet orange, pomelo, or even maybe sour orange. Where it is suspected that the stock is other than rough lemon,

it is necessary to be able to identify positively the stock in order to throw light on the present rootstock situation and to assist in the investigations now in hand.

All the above preamble explains why it was felt necessary to investigate thoroughly the methods and technique of Halma and Haas before accepting results obtained in the application of their methods in testing bark samples procured in South Africa, and to determine the colour reactions obtained with species other than the four they worked with.

MATERIAL.

Ten citrus varieties were worked on, namely sweet orange, sour orange, lemon and rough lemon (both classified as *C. limonia*), lime, naartjie (*C. nobilis* Lour.), grapefruit and shaddock (both *C. maxima* Merrill), citron (*C. medica* L.), and trifoliata. Bark material belonging to these were gathered from many areas in South Africa, samples of the same variety coming from 1,000 miles apart and from trees varying in age from 1 year to 150 years. A limited number of samples of bark of "artificial" hybrids such as tangelos, citranges, limequats, etc., and of "natural" hybrids and variants was also obtained and worked on.

Use was made of the following four colorimetric tests, the details of which are given by Halma and Haas (2):

- Modified Almen test
- Ammonium molybdate test
- Titanous chloride test
- Ferric chloride test.

Over 2,000 tests were made with aqueous extracts of ground dried bark, of ground dried root, and of dried ground leaves, and from the results obtained the conclusions presented in this paper were drawn.

In collecting bark samples it is advisable first to scrape lightly with the back of a knife the area to be cut out. This removes adhering soil particles, possible lichen growth and even such substances as old bordeaux spray which may have been applied to the tree.

The sample need not necessarily be dried in an oven. Air-dried samples gave absolutely no difference in colour reaction to those which were oven-dried. If a test is to be done in a hurry, then oven-drying will expedite matters.

No suggestion is offered as to the cause of the colour reactions obtained in these tests, but it appears to be definitely associated with the old phloem and/or the chlorophyllic tissue of the bark. Fresh lemon bark 3 mm. thick was scraped to give:—(a) the outside layers down to almost the last of the tissue containing chlorophyll, (b) the rest of the chlorophyll containing tissue and most of the old phloem, and (c) the remaining layers containing absolutely no

chlorophyll but all the young phloem. These samples were dried and tested by the aforementioned methods. Portion (a) gave extremely dense reactions, portion (b) colour reactions typical for lemon, and portion (c) no colour reaction at all. The same differentiation was found with sweet orange, although here the outer portion varied greatly in colour reaction with different samples.

Efforts to find the source of the colour reactions were carried a step farther by testing samples of leaves, twigs, bark of twigs, bark of branches, bark of the trunk, and bark of the main roots, all taken from the same tree. It was found that only the bark of the main branches and of the trunk gave reactions typical of the species.

The *depth* of colour obtained in a reaction depended greatly on the thickness of the fresh bark sample cut. Thus bark 5 mm. thick cut from the trunk of a 150-year-old sweet orange seedling gave a very much lighter colour with all reagents in comparison with bark 2 mm. thick from the main branches.

This brings us to the important point as to the influence of the age of the bark cut on the reliability of the tests. Halma and Haas maintain that the results of the tests are not influenced by the age of the tree. Where only the four species used by them are concerned, species giving clear-cut differences in colour reactions, particularly if more than one reagent is used for testing, their contention holds. However, if it is desired to differentiate between eight or nine citrus species, then it is essential that the bark samples used should all be mature and of approximately the same age. Bark varying from 1.5 mm. to 3 mm. in thickness is best.

Results obtained from testing dried leaves of many species do not indicate any possibility of using such material instead of bark in these identification methods. Nor was it found that roots or the bark of roots gave consistent reactions, thus ruling out the possibility of using this material.

No differences in reaction were obtained with bark samples which were pulverized in a mortar, ground extremely fine in a grinding mill, or coarsely ground. There is no need to sieve the powder after grinding, but if the sample is reduced in a mortar it is advisable before weighing out to remove large fractions in the resultant sample by hand or sieve.

REAGENTS.

The Almen test carried out according to Halma's modification was satisfactory. No difficulty should be experienced in making up the reagent. Five lots of reagent made up at different times gave the same colour reactions. The solution keeps indefinitely.

With the ammonium molybdate test great difficulties were encountered at first in obtaining the deep blue colour with rough lemon. It is essential in

making up the solution that the ammonium hydroxide used is at full strength. Add ordinary nitric acid (concentrated) and not fuming acid. Should the reagent when used not give a deep blue colour with rough lemon then it contains excess acid. The reagent can be used as it is for testing, but in this case the aqueous extract to be tested must first be made alkaline with a few drops of potassium hydroxide solution. The shade of colour produced with all citrus species depends definitely on the reagent being as near neutral as possible. Also, if it contains excess ammonium hydroxide, the colours obtained will vary greatly. When this reagent is made up it should be tested out with rough lemon, and a few trials will determine the amount of hydroxide to add to the extract to obtain the maximum depth of colour. The reagent deteriorates with age, especially if incorrectly made up.

Halma and Haas (2) write on this point: "Ammonium molybdate is prepared as follows: Dissolve 100 grams of molybdic acid in a mixture of 144 cc. of ammonium hydroxide and 271 cc. of water. Pour slowly into a cool mixture of 489 cc. of nitric acid and 1,148 cc. of water. Ten drops of this reagent added to the liquid and boiled will give rather consistently a deep blue colour with rough lemon and a much lighter blue or bluish grey with grapefruit. Sweet and sour orange give varying shades of green."

Titanous chloride is obtainable in solution from manufacturing chemists, generally in concentrations from 15 per cent. to 20 per cent. Any of these concentrations will give the necessary reactions. Care must be taken to keep this reagent in a dark glass bottle, as with age it is liable to change to the clear yellow tetra-chloride form, and fail to give the desired reactions. Two drops of this reagent to 5 cc. of bark extract is best. The writer found this an essential reagent to distinguish between the tangerine group and rough lemon.

Two drops of a saturated aqueous solution of ferric chloride to 5 cc. of bark extract reacts to give various shades of brown, but while with certain species the solution becomes turbid, with others it remains clear.

The use of a saturated aqueous solution of copper sulphate as a reagent is not satisfactory, as the colour differences are very slight, there oft-times being greater variation within a species than between species.

RESULTS OBTAINED.

In the accompanying Table are given the colour reactions obtained with the four reagents used on many species and varieties of citrus. It was often found that samples belonging to one species, such as the sweet orange, showed great variation, chiefly in depth of colour or shade, with certain reagents. Where two species give approximately the same reaction with any particular reagent it is found that in most instances one of the other reagents will separate such species.

Colour reactions obtained with bark of citrus species.

Sample.	Almen test.	Ammonium molybdate test.	Titanous chloride test.	Ferric chloride test.
Rough Lemon	almost colourless	deep blue	almost colourless (pink tint)	light straw/brown (clear)
Grapefruit	light brown/pink	light green (blue-grey tint)	very light brown/grey	straw brown (clear)
Tangerine (Naartjie)	almost colourless	light blue	almost colourless (pink tint) (turbid)	light brown (turbid)
Sweet orange	pink	green	light straw-green (turbid)	brown (turbid)
Sour orange (Bitter Seville)	light brown	light green	light brown-green	brown (clear)
Shaddock	almost colourless (purple tint)	light blue	almost colourless (brown tint)	light brown (slightly turbid)
Citron	very light brown	dark green	light brown	brown (clear)
Lime	light pink	blue (slightly turbid)	almost colourless	light brown (clear)
Lemon	dark brown	green	dark green	dark brown (clear)
P. trifoliata	almost colourless (green tint)	green	almost colourless (brown tint)	brown (clear)
Kumquat	almost colourless (green tint)	light green (blue tint)	colourless	brown (clear)
Tangelo	light pink	green	light brown/green	dark brown (slightly turbid)
Citrange	light pink	green	light brown/green	dark brown (clear)
Citrus mitis	deep pink	very dark green	very dark green	black brown (clear)
Limequat	light brown	green (blue tint)	very light brown/green	brown (clear)

When testing an unknown bark sample it should be possible by referring to the table to identify it in most instances. For example, if with the Almen test an almost colourless reaction is obtained, further tests with the other reagents

will have to be made. It is noticed that rough lemon, tangerine, shaddock, trifoliata and kumquat all give a similar reaction with Almen. The various tints do not appear in all samples tested, and can thus be regarded only as indicative. Reference to the molybdate test separates rough lemon, tangerine and shaddock into one group (blue reaction), and kumquat and trifoliata into another (green reaction). With both titanous chloride and ferric chloride the tangerine is separated from the others on account of its turbidity ; rough lemon is distinguished from shaddock by the former's deeper shade in the molybdate test and lighter shade in the ferric chloride test ; the kumquat is distinguished from the trifoliata by the former's colourless reaction with titanous chloride. This latter is quite apart from the very great morphological differences between trifoliata and kumquat, when considered as trees or as rootstocks.

It was not possible to differentiate by these methods between bark samples of the tangelo and the citrange, both " artificial " hybrids. Both these have two entirely different parents. The colour reactions given by hybrids showed no correlation with the reactions obtained with the known parents. It was further found that what are apparently " natural " hybrids showed no correlation with the suspected parents. Unfortunately the number of samples available for this phase of the investigation was limited, but results obtained indicate that it is doubtful if the parentage of hybrids can be determined by colorimetric tests on their bark.

Halma and Haas have drawn attention to the striking differences given in colour reactions by rough lemon and the standard lemon. As can be seen from the Table, in all tests these two varieties of *C. limonia* fell wide apart, and it seems that even though, because of their morphological characters, these two varieties are included in the same species that they may be two distinct species. The shaddock and grapefruit are often both included in *C. maxima*, but here again their different reaction to colorimetric tests suggests that they are probably distinct species. Hume (5) does refer to grapefruit as *C. paradisi* Macf. and to shaddock as *C. maxima* Merrill.

In conclusion, the writer wishes to express the following opinions, based on much orientation work and on the work reported here, regarding the identification of citrus species by means of colorimetric tests.

It will not be until the actual source and cause of the colour reactions is determined that these identification methods will become absolutely reliable and of very much greater use than now. When the constituent or constituents of the bark which react are known and can be determined quantitatively, an investigation as to their content in all known species of citrus, in hybrids and in various portions of the same tree should provide information which will allow modifications in technique of the present methods to make them reliable at all times.

It should not be inferred that these methods of identification as known to-day are of not much value. On the contrary, they are a distinct contribution to citricultural science. This paper brings out the fact that their use must necessarily be restricted to a limited range. When it is definitely known that a certain sample belongs to one of several known species, and the bark and method of gathering was normal, then in practically all cases it should be possible to make a definite identification.

Appreciation of the assistance rendered by Mr. H. van Elden during this investigation is expressed.

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THE METABOLISM OF FRUIT AND VEGETABLES IN RELATION TO THEIR PRESERVATION*

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THE ideal of modern preservation of fruit and vegetables has within recent years widened its basis. Its requirements extend now beyond the guarding against parasitic attacks and other external influences, it seeks to regulate the normal plant metabolism by inhibiting or accelerating at will the various metabolic stages.

The use of ripening agents, such as ethylene, acetylene and their chlorohydrins as well as other halogen derivatives (1), led to definite progress by linking the new methods with the agents actually operating under normal conditions of plant growth.

No such direct connection can, however, be traced between the natural inhibitors regulating the various stages of metabolism and the inhibiting conditions and agents as low temperatures below the toleration point, modified atmospheres, slaked lime, charcoal, peat, sand (2) and still less various antiseptics employed in the processes of preservation. Thus whilst moderate reduction in temperature and concentration of oxygen accompanied by increase in the carbon dioxide content, introduction of ozone and improved ventilation represent increasingly successful conditions of preservation—the artificiality of many methods of storage is well demonstrated by the “soft scald”, tissue distortion, loss of flavour, acetaldehyde and ethyl-alcohol formation (3), irreversible suppression of metabolism developed during storage—the underlying causes of which were hitherto not quite apparent.

In the present paper new conditions of preservation are described, which seem to constitute the nearest, hitherto attained, approach to natural inhibiting influences, and throwing light on the mechanism of some important phases of metabolism.

EXPERIMENTAL.

POTATOES.

Experiment I.

1 kg. of dry King Edward potatoes, selected to show signs of sprouting, were placed on a double layer of tissue paper in a chip basket and sprayed with 10 ccs. of a 1 per cent. solution of maleic acid in amyl acetate. The potatoes

* Preliminary Note—Chem. & Ind., 1935, 54, 283.

were then well covered with two layers of tissue and brown paper, and the basket was placed on dry sand in a fairly well ventilated cellar at a temperature ranging from 11° - 12.5° for a period of 4 weeks. At the end of this time the potatoes were examined. The loss in weight was found to be slight and the indication of sprouting originally noted had actually receded. No mould or decay was observed. The potatoes retained their normal flavour when boiled.

Untreated potatoes of the same variety, kept as controls under identical conditions, were found to be vigorously sprouting.

Similar results were obtained with Majestic and Great Scot potatoes and the efficiency of the treatment was found to be unaffected by the substitution of amyl iso-valerate, oil of lemons or oil of oranges for amyl acetate.

It was observed that the maleic acid-treated potatoes kept for a longer period began to show signs of sprouting at the end of 8 weeks, these becoming more pronounced during the next fortnight.

When at the end of 4 weeks, the treated potatoes were soaked in tepid water, rinsed and placed under the same conditions as the controls, they were found to sprout normally.

Substituting the maleic acid-etherial oil solution by solutions of fumaric acid of similar concentration, the sprouting, mould and decay were found to have slowed down as compared with the controls, but no total inhibition was effected. The spraying with esters alone was still less efficient.

Experiment II.

Experiment I was repeated, the potatoes being sprayed with 10 ccs. of a maleic acid emulsion the bulk of which was prepared as follows: 1 gram of finely powdered maleic acid was dissolved in the least quantity of aqueous gum acacia, the volume made up to 100 ccs. with amyl acetate, the ester being added gradually with vigorous shaking. The shrinking and loss in weight of the so treated potatoes was found to be reduced, whilst the inhibition of germination was maintained.

Using emulsified maleic acid in which the ratio of ester to water was less than 2 to 1, the potatoes began to show signs of sprouting and decay at the end of a 4 weeks' period.

The loss of moisture may also probably be prevented by employing peat in conjunction with a sand base, a modification of a process employed by Smith (2).

Experiment III.

Substituting in Experiment I the etherial oil solution by 10 ccs. of a 1 per cent. aqueous solution of maleic acid, the activity of the inhibiting agent was found to be more fugitive. During the first fortnight definite recession of

germination was noted, but on prolonging the period, the action of maleic acid practically ceased—sprouting slowly coming into being as well as signs of decay and mould.

Employing an aqueous solution of fumaric acid, no suppression in the growth of fungus could be noted, and at the end of the period, sprouting was found to be well advanced but with signs of abnormalities.

Experiment IV.

Three 2 kg. lots of carefully selected Newtown pippin apples, (a) green—unripe, (b) yellow—mature, and (c) apples of advanced senescence—yellow to brown, with dark fermenting patches, were separately peeled, cored, minced and each immediately extracted with 2 litres of ether. The solvent was then removed and each residue emulsified with a few drops of gum acacia and 10 ccs. of amyl acetate.

Spraying three 1 kg. lots of potatoes with the so obtained three etherial apple extracts under conditions identical to those adopted in Experiment I, the following results were obtained. (a) Treated with extract from unripe apples—no sprouting was observed, (b) with extract from mature apples—slight signs of stumpy sprouting, and (c) extract from over-ripe apples—somewhat abnormal but definitely more vigorous sprouting, as in the case of essential oils without maleic acid.

Similar results were obtained by employing extracts from unpeeled apples.

An aqueous solution of the ether extract residue from the unripe apples (a) was found to be similar to aqueous solution of maleic acid, i.e. effective, but more fugitive in its inhibiting action on the germination of potatoes.

This appears to be in full agreement with Kockemann's experiments (9) on the isolation of the natural inhibitor from apples and that of Elmer (15) on the variation of the inhibiting activity of apples with their stage of ripening.

It also shows the suppression of germination by maleic acid and by the active principle of apples to be practically identical, both qualitatively and quantitatively on the basis of the ratio of maleic acid to ethylene.

APPLES AND OTHER FRUIT.

Experiment V.

1 kg. of unripe apples, Newtown pippin variety, were sprayed with 10 ccs. of a 1 per cent. maleic acid solution in amyl acetate under conditions of Experiment I and kept for a period of 8 weeks. Examination showed the apples to be unchanged in colour, taste and hardness. There was some loss in weight, the skin showing signs of wrinkling. Using maleic acid emulsion (Experiment III) the loss in weight was reduced.

Similar results were obtained with unripe Red Jonathan apples and Josephine pears (imported and history unknown)—blushing and yellowing being entirely suppressed.

Controls kept for the same period showed progressive change of colour, maturing, signs of browning, decay and fungus growth.

Substituting amyl acetate by amyl iso-valerate did not affect the efficiency of the maleic acid.

Unripe green Jamaica bananas, similarly treated for a period of 4 weeks, remained unchanged in appearance, taste and hardness, controls, however, becoming yellow, soft and sweet.

The action of etherial oil solution of the apple extract (Experiment IVa) on unripe fruit was found, similar to maleic acid, to inhibit ripening.

As in the case of potatoes, aqueous solutions of maleic acid were found to be unstable in their inhibiting effect on fruit.

Experiment VI.

A series of experiments were carried out with selected ripe fruit as follows:

Apples, pineapples and bananas were treated with a 1 per cent. solution of maleic acid in amyl acetate, whilst (1) Jaffa oranges and (2) lemons and grapefruit were sprayed with similar solutions of maleic acid in oil of oranges and oil of lemons respectively under conditions adopted in Experiment I (except the bananas, which were kept for a period of 2 weeks).

In all cases, decay and mould were eliminated and softening considerably reduced as compared with the controls.

DISCUSSION.

The scope of the experiments described in this paper and their interpretation, both as regards the course of plant metabolism and the problem of preservation, will probably be best understood in the light of earlier researches on the subject.

The presence of an inhibiting substance in the food-storing layer of the fruit as distinct from glucosides and alkaloids was first recognized by Wiesner in 1894 (4). Further progress was made by Gassner (5), Heinricher (6), Oppenheimer (7) and Reinhard (8).

A more detailed study of the problem was carried out by Kockemann (9), who found the inhibiting principle to be general to the food-storing portion of the fruit and observed its properties to correspond to those of an unsaturated acid. The term "blastokolin" was proposed for this inhibiting substance.

The experiments of Shuck (10) showed this inhibitor to be present not only in fruit but also in seeds, such as lettuce seeds, apparently conditioning dormancy.

The general distribution of this substance, regulating the normal course of metabolism and exerting a protective influence against parasitic attacks, is shown by its occurrence in the more stable types of fats and vegetable oils—thus constituting in reality one of the differentiating principles in the various grades of this class of products in their liability to rancidity (11).

In the study of fruit metabolism it is essential of course to recognize not only the precise nature and extent of functions of both the natural accelerator and inhibitor, but also their interrelation and the role played by them in each specific phase of fruit development.

From the work of Gane (12) on apples and Nelson and Harvey (12) on the self-blanching celery, we find the natural volatile accelerator to consist mainly, if not exclusively, of ethylene. It is evolved during the maturity period, gradually fading towards senescence. Its function appears to be dual. In the food-storing portion of the fruit it accelerates ripening by increasing respiration (1) and the conversion of the starch granules into reducing sugars (13). This is apparently accomplished by the selective activation of amylase by ethylene (14).

On embryonic development, ethylene however exerts an inhibiting effect, suppressing the germination of seeds and sprouting of potatoes (15). Results of an opposite character were recorded by Werner (16). This effect is temporary and apparently narcotic in nature (17)—the germination proceeding unimpaired on removal of the gas.

The acid inhibitor—"blastokolin"—on the contrary, as may be seen from Experiment IV described in this paper, suppresses not only germination, but also respiration or ripening.

Now whilst the accelerator occurs in the maturity to senescence period (12 and 15), the inhibitor is found in the unripe to ripening stage (see experiments).

Co-ordinating these observations, it appears that the first physiological relationship between the inhibitor and accelerator is that the former's functional decline or actual disappearance is concomitant with the evolution of the accelerator.

The significance of this relationship goes, however, beyond mere consecutiveness. If we consider the points of contact between "blastokolin" and maleic acid on one hand, and maleic acid and ethylene on the other, we find we are dealing with a direct chemical degradation accompanied by a corresponding functional change.

Both the natural inhibitor and maleic acid are unsaturated acids having many properties in common and both suppressing not only rancidity but also respiration and germination. Again, maleic acid (1) is not only constitutionally related, but is in fact a link in a chain of partly reversible reactions, involving

a group of *naturally occurring* di- and tri-carboxylic saturated and unsaturated acids (2) inhibits the sprouting of potatoes and the ripening of fruit and (3) exerts a bactericidal and fungicidal influence apparently suppressing peroxide formation, being non-toxic and effective in this respect in minute quantities as 1:10,000 in fats and edible oils (11). It would thus appear not improbable that maleic acid is actually produced during the metabolism of fruit, and is intimately connected, if not identical, with the *naturally occurring* inhibitor—"blastokolin" (9).

The very evolution of ethylene during the maturity period of apples lends additional support to this view. The degradation of maleic acid to ethylene and carbon dioxide under the influence of enzymic activity is not only constitutionally possible, but such a course of catabolism has its analogies in the formation of ethylene by auto-oxidation (together with CO_2 and small quantities of CO) and pyrogenic decomposition of plant materials (18), electrolysis, dehydration, etc.

If we consider the minute quantity of ethylene produced during the apple metabolism (1 cc. per apple (12)), we find 1 cc. $\text{C}_2\text{H}_4 = 0.00126$ grams to correspond to 0.005 grams of maleic acid which represents a concentration of 1:20,000 in an average 100 gram apple. This concentration compares favourably (allowing for excess as safety margin) with the tested potency of maleic acid (1:10,000) as an inhibitor of rancidity in fats and edible oils (11). We thus obtain a quantitative link between ethylene and maleic acid, which not only supports our conception, but also in some measure explains the hitherto failure of detecting the transitory traces of maleic acid in apples.

These considerations suggest the following mechanism of reaction in this particular phase of metabolism. During the period of fruit ripening and embryonic development, enzymic activity is greatly enhanced and differentiated. Apart from the remarrying of already existing saccharides and polysaccharides (19), many more come into being and the saturated acids are converted under the influence of dehydrases in part into physiologically active unsaturated acids.

Having served its specific purpose in the scheme of fruit development by synchronized retardation of both respiration and germination, as well as those of parasitic attacks, the natural inhibitor "blastokolin", or as we assume with a fair degree of justification, maleic acid is broken down by a phase of enzymic catalysis into ethylene and carbon dioxide.

The small quantity of inhibitor originally present, its protracted degradation and the presence of comparatively large quantities of other gases in the fruit tissue all ensure for ethylene the required dilution to act as a ripening agent on the food section of the fruit, while exerting at the same time a halting narcotic effect on the growth of the embryo (17).

The complex ramification of inter-cellular spaces, the intra-cellular gas occlusions and the poor porosity of the skin retard the diffusion of ethylene, introducing a gradient of concentration and giving it a sufficient period for its function within the fruit.

As in many other instances the metabolism of fruit may be viewed as a closed cycle of cause and effect. Brought into being by enzyme action—ethylene itself influences amylase (14), thus hastening the conversion of the starch granules into reducing sugars, with consequent change of colour and fruit softening, thus preparing both a path and nutrient medium for the embryo now released from its dormancy. The fruit softening is apparently also enhanced by conversion of insoluble pectic substances, principally protopectin, into a soluble form (20).

It is important to note here that, although the food-storing portion of the fruit during its senescence seems to become entirely vulnerable to parasitic attacks, the glucosides and alkaloids, amygdalin, solanidine, solanthrine, etc. (21) accompanying the developing embryo, are as a rule sufficient to protect the germinating seed.

Dealing with the experimental findings recorded in this paper, it would appear that the greater efficiency of maleic acid in etherial oils as compared with aqueous solutions of equal concentration, is perhaps contrary to expectations on the basis of its ionization in water and organic solvents. But if we note the minimum antiseptic values of maleic acid, viz.:

0.06% in aqueous solution (22),

0.036% in a yeast extract-peptone-agar medium (23) and

0.001% in fats and oils (11)—

it appears that maleic acid has a greater penetrability when in organic solvents through the fatty membrane of putrefying organisms and their spores, as compared with its aqueous solution.

Again in our experiments the question of accessibility must be of paramount importance, and in this respect the high vapour tension of organic solvents ensures a uniform acid bearing atmosphere.

Furthermore maleic acid in an aqueous solution may be expected to be more fugitive in character, as with increased dissociation, it is more liable to undergo isomerization or pass into the inactive saturated acids.

Although representing the nearest approach to natural conditions, essential oils are as a solvent medium for maleic acid probably not indispensable, and may be substituted by other organic solvents of suitable vapour tension, odour, taste, etc.

In their study of "scald" in stored apples, Brooks, Cooley and Fisher (24) suggest the possibility of injury to the fruit by the vapour of its etherial oils under conditions of storage. However, the experimental data put forward by

them do not bear out the validity of this statement—the injury to the fruit being in all probability due to the non-removal of acetaldehyde (25) and ethylene.

The usefulness of oiled wrappers for fruit is attributed by these authors not only to their effect upon fruit respiration but also their ability to absorb the injurious etherial oils. And yet their own figures as to the difference in protective efficiency of paraffin and mineral oil wrappers (the latter giving much better results against "scald") suggest to us that the effectiveness of oiled wrappers is in the main due not to the adsorption of the esters, but to the antiseptic properties of oils impregnating the wrappers.

Considering the carcinogenic character of many mineral oils as well as the detrimental action of these substances upon enzymes—paraffin oil wrappers containing maleic acid might have the preservative advantages of mineral oils without their obvious drawbacks.

Whilst the etherial oils described in this paper as media for maleic acid are inert, some esters may of course be found which in virtue of their chemical constitution exhibit antiseptic and other properties (26).

As to their influence upon the flavour and palatability of the preserved fruit, this problem hardly arises if the etherial oil medium of the maleic acid is adjusted to the natural flavour of the fruit, and the relative quantities employed kept under control.

In case of potatoes—commercial conditions of storage may warrant the reduction in ratio of esters to the bulk of material or their substitution by some other odourless organic medium, thus mitigating the effect on flavour.

Whilst obviously further detailed research is necessary in applying these results to commercial conditions such as transport, storage in bulk, relative advantages of fumigation and specially treated wrappers, temperature and ventilation—their possible application may extend beyond fats, edible oils and cereals (11) to the preservation of tomatoes, grapes, berries, fermenting juices (wine, cider) and caviare (27).

SUMMARY.

The experiments recorded in this paper show:

1. Maleic acid inhibits the processes of ripening and germination, as well as parasitic activity, in a variety of fruit and potatoes.

This suppression of metabolic functions is temporary in character and does not appear to exert any injurious effect. Maleic acid is much more effective in an inert etherial oil than in an aqueous medium, in which it is apparently unstable under the experimental conditions employed.

2. Etherial extracts of apples, freed from the solvent and dissolved in inert esters, exert an inhibiting influence upon embryonic development and respiration of fruit and potatoes similar to maleic acid.

3. Co-ordinating (a) the chemical and physiological similarity between maleic acid and the natural inhibitor, (b) the succession of the inhibitor at the maturity stage by ethylene as an accelerator and (c) the constitutional link between maleic acid and the acid-fruit constituents, as well as its possible degradation to ethylene, it is not improbable that maleic acid is identical with the natural inhibitor "blastokolin", and the transition of this inhibitor into the accelerator is represented by the degradation of maleic acid into ethylene.

This conception not only elucidates an important phase in fruit metabolism, but has a direct bearing on the problem of fruit and vegetable preservation.

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VARIATION IN THE "PARADISE" APPLE ROOTSTOCKS

A STUDY OF SOME LEAF AND SHOOT CHARACTERS IN FOUR RACES

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It has been an invariable practice at this Station that all serious research into problems connected with the cultivation of fruit trees has been preceded by studies of the comparative morphology, classification and nomenclature of the varieties in common use. This practice has been amply justified by the result, since frequent instances have been encountered, both in the case of the tree and of the small fruits, of the same name being used to describe widely dissimilar forms, and of different varieties being cultivated and distributed under the same name.

In November 1912 work was commenced at East Malling on the classification of the "Paradise" apples. Of widely diverse origin, these varieties of apple had been in use for varying periods as rootstocks for apples. As the work of Hatton revealed, considerable confusion existed as to the correct nomenclature of the varieties, and ideas were correspondingly vague as to their potential influence over the scion variety worked upon them. In 1917, Hatton published the results of his authoritative classification studies (1), and careful comparative descriptions were given of the leaf, shoot and root characters of nine varieties, supplemented in 1919 by descriptions of the blossom and fruit characters (2). Hatton stated that of 70 collections received from various sources in this country or on the Continent, only 45 were true to name, the remaining 25 being mixed. In the case of No. II, Doucin, 32 collections were sent from 30 different sources in England, France, Germany and Holland of which 21 were true while in the case of No. IX, Jaune de Metz, 5 collections were sent from 2 sources in France and Germany of which 4 were true to name. When, after careful comparison, these true collections had been found to be botanically indistinguishable, they were grouped together as Malling No. II and No. IX respectively. They were established as stools, being cut down and mounded up in the usual way. The possibility has always been borne in mind that these grouped collections, more especially those of No. II, may consist of a mixture of varieties so closely similar botanically as to be distinguishable only with the greatest difficulty. Closely analogous cases of botanically similar

varieties of different genetical constitution and potential fruiting capacity have been encountered in both black currants and raspberries. Nevertheless careful observations extending over twenty years have failed to reveal any appreciable differences between the plants within these groups either with regard to their morphological characters or in the growth and cropping of the sets of trees of which they have come to form the root systems (3, 4). In order to make certain, however, that material being raised for special experimental purposes was uniform and pure beyond any question of doubt, races of a number of the Malling series of rootstocks were raised by repeated vegetative multiplication from a single selected individual. These races, which were started in 1927, have now grown to considerable dimensions, and have come to be known as the Malling Reselected Clones. In general, this material has been reserved for experimental purposes, and only material from the older stoolbeds containing the grouped collections has been distributed. Reports have been received occasionally that slight morphological variations have been discovered in such material from the grouped collections when growing elsewhere, and considerable interest has been evinced from time to time as to the possibility that such a reselection from a single individual might not merely have reduced the variation with regard to the characters of the resultant vegetative progeny but also to some extent have altered the characters when compared with those of the progeny from stools of the grouped collections. The present study was undertaken to determine whether any such differences with regard to certain well defined morphological characters of the vegetative shoots arising from the stools could be ascertained.

CHARACTERS STUDIED.

It was obvious that for the purpose in view only characters that could be easily and exactly measured would be suitable, and the following were selected as being as far as possible representative of the vegetative shoots during summer.

(a) *Shape of Leaf*. The maximum breadth of the leaf and the distance from the apex of the leaf to the point at which the maximum breadth occurs were measured. These two measurements give an approximate estimate of the shape of the leaf. Each was expressed as a percentage of the maximum length of the leaf to make comparison possible.

(b) *Length of the Leaf Stalk*. This was expressed as a percentage of the maximum length of leaf.

(c) *Number of serrations around the Leaf Margin*. There is no evidence that this character varies with the size of the leaf.

(d) *Length of the Stipules*. The stipules on either side of the leaf stalk were measured, averaged and expressed as a percentage of the maximum length of the leaf.

(e) *Taper of the Apex.* The breadth of the leaf apex at one centimetre below the extreme tip was measured. This expressed as a percentage of the maximum breadth of the leaf expresses the sharpness with which the apex of the leaf tapers.

(f) *Number of Lenticels.* The number of lenticels upon a measured 10 centimetres of wood, 15 centimetres from the top of the shoot, were counted.

THE MATERIAL.

The observations were in all cases made on material from the one year vegetative shoots arising from the stools. In the first place twelve leaves (the fifth to the sixteenth inclusive) were taken from each of ten shoots upon a single stool of No. II (grouped collections); No. II (reselected clone); No. IX (grouped collections); and No. IX (reselected clone). From an analysis of the measurements of these leaves it was hoped to be able to compare the variation from leaf to leaf and from shoot to shoot upon the same stool with that between the stools in these four races. In the second place, three leaves (in each case the tenth, eleventh and twelfth) were taken from each of ten shoots upon each of ten stools selected at random from a large number from the two races of No. II and of No. IX.

It should be made clear at the outset that the stools from which these leaves were taken were all seven years old, in good growth and that the shoots were of approximately equal size. It is not easy to obtain a measure of the absolute size of the leaves from the measurements which were taken. Taking absolute length of lamina as a rough criterion of leaf size variation was found to be comparatively slight from leaf to leaf upon the same shoot, ranging from 5.5 per cent. in the case of No. IX (reselected clone) to 11 per cent. in the case of No. II (reselected clone). While comparable data for the variation from shoot to shoot have not been calculated an inspection of the figures suggests that the variation was somewhat greater.

THE RESULTS.

The results of these observations are summarized in the Table. The coefficients of variability as a percentage of the mean, have been calculated in the case of four of the characters studied. The work of calculation was so laborious and the results so inconclusive that it was not considered worth while to calculate them for the remaining characters.* As far as they go the figures in the Table furnish little evidence that there is any appreciable difference in the expression of the characters studied between the grouped collections and the reselected clones of either No. II or No. IX or that the amount of variability

* The writer's grateful thanks are due to Miss J. L. Edgar for undertaking the laborious task of calculating these coefficients and for testing the statistical significance of the results.

12 leaves from each of 10 stools from a single stool in each case.

	Maximum breadth of Lamina.		Apex to point of maximum breadth.		Length of Leaf Stalk.		Length of Stipules.		Number of serrations on Leaf.		Breadth of apex expressed as a percentage of maximum breadth of Lamina.		Number of lenticels in 10 centimetres of wood.	
	II.	IIR.	II.	IIR.	II.	IIR.	II.	IIR.	II.	IIR.	II.	IIR.	II.	IIR.
<i>Malling No. II.</i>														
General Mean	65.71	65.51	50.51	54.29	32.57	30.37	6.48	7.11	70.62	79.72	15.85	13.80	—	—
<i>Coefficient of Variability:</i>														
Within stools	6.8	5.8	7.9	6.2	10.2	8.0	—	—	7.2	6.2	—	—	—	—
Between stools	10.2	9.5	10.4	12.7	29.1	8.2	—	—	22.6	21.1	—	—	—	—

3 leaves from each of 10 stools from each of 10 stools in each case.

General Mean	66.59	65.88	51.77	52.91	31.72	31.17	6.86	6.86	77.15	77.93	12.71	12.39	82.80	78.31
<i>Coefficient of Variability:</i>														
Within stools	5.5	6.1	7.6	6.8	10.4	11.4	—	—	9.6	7.7	—	—	—	—
Between stools	14.7	12.1	8.3	13.6	28.5	35.6	—	—	21.1	18.1	—	—	—	—

12 leaves from each of 10 stools from a single stool in each case.

	IX.		IXR.		IX.		IXR.		IX.		IXR.		IX.	
	IX.	IXR.	IX.	IXR.	IX.	IXR.	IX.	IXR.	IX.	IXR.	IX.	IXR.	IX.	IXR.
<i>Malling No. IX.</i>														
General Mean	64.29	67.93	60.91	56.78	31.72	28.62	7.83	9.71	76.89	83.87	11.76	11.44	—	—
<i>Coefficient of Variability:</i>														
Within stools	4.4	5.1	7.2	4.6	9.1	13.6	—	—	6.6	5.5	—	—	—	—
Between stools	12.9	13.4	7.1	5.4	17.5	18.2	—	—	12.3	10.2	—	—	—	—

3 leaves from each of 10 stools from each of 10 stools in each case.

General Mean	66.36	67.62	56.26	56.91	29.40	27.00	8.09	8.86	75.01	82.94	12.98	10.73	10.91	11.26
<i>Coefficient of Variability:</i>														
Within stools	6.2	6.2	5.6	5.0	12.2	11.5	—	—	7.4	7.6	—	—	—	—
Between stools	18.7	10.1	9.5	9.2	23.5	22.4	—	—	18.5	12.6	—	—	—	—

R=Resected clones.

is significantly greater in the one case than the other. Certain cases may be picked out which do not entirely confirm this view. Thus, the average distance from the apex of the leaf to the point of maximum breadth is somewhat greater in the case of the reselected clones of No. II than in the case of the grouped collections, but the reverse is the case with the two races of No. IX. The leaf stalks of the reselected clonal races of both Nos. II and IX appear to be, on the average, slightly shorter and the serrations round the leaf margin somewhat more numerous than in the case of the grouped collections. Such differences are, however, extremely slight and probably fortuitous. In three cases there is a statistically significant difference in the amount of variability between the stools when the reselected clonal race and the grouped collections are compared but the lesser amount of variability is not always found in the reselected clonal races; in one case the reselected clone is significantly more variable than the grouped collections.

While, therefore, it may be said with a fair degree of safety that the twenty-one collections of No. II and the four collections of No. IX, which were grouped together to form the earlier lines of these two rootstocks, upon the completion of the classification work, were in the main identical at least with regard to the seven characters studied by the writer, it must be remembered that the unit studied (10 stools in each case) was not large and that an admixture occurring in less than 10 per cent. of the stools might have stood a good chance of being missed. Upon the other hand the results of the present study indicate that serious admixture cannot be present in more than 10 per cent. of these stools. It was obviously of the first importance to study the expression and variability of a number of characters, since forms might differ with regard to one character and not with regard to another; it was equally important in such a case that the samples should be sufficiently numerous to be representative of the whole. While a sample of ten individual stools would be hardly likely to discriminate the occasional "rogue", if such existed within these races, it seems probable that, had different collections consisting of different but closely similar varieties been present when the original grouping took place the sample taken was adequate to have disclosed this fact.

It is perhaps noteworthy that there are such large differences in the amount of variability when calculated from leaf to leaf upon the same shoot and from shoot to shoot upon the same stool. This is closely paralleled in the case of the stools, the amount of variability between the shoots upon a single stool being frequently less than one half that between the stools. In the majority of the shoots studied a consistent gradation in the variation for leaf shape and other characters could be traced. Thus the leaves became progressively broader, the leaf stalks shorter, the serrations round the leaf margin fewer as one proceeded from the apex of the shoot to its base. For this reason only certain

leaves towards the middle of the shoots were selected for the study of the comparative variation from stool to stool. It is somewhat surprising, therefore, to find that even when such comparatively large variations from leaf to leaf upon the same shoot are taken into account, the variation from shoot to shoot upon the same stool should be so much larger. It is not so difficult to see the reason for the much greater variability from stool to stool when compared with that from shoot to shoot upon the same stool taking only comparable leaves into consideration.

Little or nothing is known as to the variability to be anticipated from such lines of clonal rootstocks. As vegetatively propagated units of a single individual it may be assumed that they are genetically identical apart from the possibility of occasional mutation, and that the inherent variation should not be greater than that to be found in a single tree or in a single homozygous pure line raised from seed. However, each stool, as well as being a part of a genetically identical pure line, is also an individual and as such, subject to "fluctuations" due to environmental factors. Probably a great part of the variability within the stool as well as the whole of the much greater variability from stool to stool is attributable to this source.

The present study does not claim to be in any way exhaustive or to present a complete picture of the variation in the lines of rootstocks studied. So far as it has been possible to go, however, support is lent to the view that reselection from a single individual has neither decreased the variability nor markedly altered the expression of the characters studied in either of the races of rootstocks dealt with.

The writer's thanks are due to Mr. R. G. Hatton for suggesting this study and to Messrs. N. H. Grubb and T. N. Hoblyn for much helpful advice.

SUMMARY.

This paper summarizes the results of a study made upon the shoots arising from the stools of two races, the original grouped collections of botanically similar rootstocks and reselected clones raised from a single individual of "Paradise" apple rootstocks, Mallings Nos. II and IX.

The characters studied were leaf shape (the length $\times$ breadth relation and the distance from the leaf apex to the point of maximum breadth), the length of the leaf stalk, number of serrations around the leaf margin, the length of the stipules, taper of the leaf apex and the number of lenticels in the wood. While it was made clear that the data presented was not adequate to give a complete picture of the variation within these races, the results obtained confirm the view that neither the amount of variation nor the expression of the characters is appreciably different in the two races of either of the rootstocks.

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VARIETIES OF CABBAGE LETTUCE AND THEIR CLASSIFICATION

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THE popularity of cabbage lettuce as a salad has greatly increased of recent years. In the pre-war years it was almost impossible to sell a cabbage lettuce after the beginning of May, and the demand for cos lettuce was very great. To-day the situation is reversed, and there is a ready sale for cabbage lettuce at all seasons. We find that while the number of varieties of cos lettuce seed available is considerable, it by no means approaches the number of varieties of cabbage lettuce.

Confusion among varieties is increased by the fact that, in many cases, similar lettuces are named differently by different seedsmen. This situation is no new one; in the *Gardeners' Chronicle* for January 16th, 1869, an anonymous correspondent wrote "the evil of rechristening is operating more extensively among lettuces than among any other class of vegetables. In the winter of 1866-67 a fine, new and somewhat distinct lettuce was put into circulation for the first time; and there is reason to believe that the self same kind is this winter appearing under two or three different names". To-day this evil is, if anything, worse.

In the course of investigations by L. Ogilvie and the present writer on a Mosaic disease of lettuces, which is at present very severe in the West of England, it was found that the response to infection by this disease varied greatly among the different varieties of lettuce. In studying this aspect of the disease one immediately felt the necessity for some classification of varieties, and determination of synonyms. This work was undertaken to satisfy the need.

PREVIOUS SYSTEMS OF CLASSIFICATION OF CABBAGE LETTUCE.

Several attempts have been made to classify the numerous varieties of lettuce, but none have been more than partially successful. The most commonly used basis for classification is the usual season and method of cultivation. On this basis lettuces may be divided into summer and winter outdoor varieties, and spring protected sowing varieties. This method is partly satisfactory in that many obviously related lettuces can be grouped in this way. One of the best attempts at lettuce classification in this manner is that of Lester Morse—"Field Notes on Lettuce" (5)—but unfortunately very few of the modern European varieties of lettuce, particularly English varieties, are dealt with.*

* This method of classification is also used in Ministry of Agriculture Bulletin No. 55—"Salad Crops", where many synonyms of lettuce varieties are also given.

But this basis of classification is seen to be inadequate in that many varieties might with equal justification be put into more than one class. For example *All the Year Round* may be successfully sown out of doors at all times of the year ; again *May King* may be grown in the open in winter, and proves quite hardy, is commonly sown outside in the spring, and is also a useful lettuce for growing under glass in the spring.

In 1919 the Royal Horticultural Society (6) adopted a classification for lettuces used in their Wisley trial, which was frankly artificial. Such characters as seed, colour and presence or absence of anthocyanin colouring in the leaves, were used for determining main divisions in the classification. This had such results as to group together such forms as *May King* and *Stanstead Park*, and to separate such obviously related forms as *Trocadero* and *Unrivalled*.

A really successful classification of cabbage lettuce varieties must take account of the fact that there are several quite large groups of lettuce of similar general appearance, such as the well-known group of Gotte lettuces, and any classification which splits such natural groups must be discarded. The value of such characters as presence of anthocyanin, seed colour, and season of sowing, must be determined by an analysis of their occurrence in varieties of cabbage lettuce, and of their genetical constitution. Towards this end it is intended in this paper to consider all the more striking differences observable in numerous varieties of lettuce and to evaluate their use in classification.

CHARACTERS SUITABLE FOR CLASSIFICATION OF CABBAGE LETTUCE.

Seed colour.

Strictly speaking we are not here dealing with a "seed" in the botanical sense, but with a type of fruit known as an achene ; that is to say the "seed coat" is formed from tissues of the female parent plant. Three types of seed colour are known—black, white and yellow. The last colour is quite uncommon and does not occur in any commonly grown lettuces. *Yellow Seeded Butter* and *Magnum Bonum* are yellow seeded varieties grown occasionally in the United States.

Some knowledge of the inheritance of seed colour in crosses from black seeded and white seeded parents has been obtained by C. E. Durst (3) (1920). In his crosses he used two black seeded parents, *Grand Rapids* and wild *Lactuca scariola* and the white seeded parents *May King* and *Big Boston* and *Paris White Cos*. In every case the seed produced as a result of the cross fertilization was of the same colour as that of the female parent ; this is due to the circumstance already mentioned, that the outer layer of the "seed" is derived from tissues of the female parent. All the plants in the F_1 generation produced black seed. In the F_2 and F_3 generations black and white seeded forms were

produced in the ratio of 3:1. It would appear, therefore, that in the case of black and white seeds, seed colour is controlled by a pair of allelomorphic factors, that for black being dominant to white. Durst also found that all the wild forms of *Lactuca scariola* that he examined produced black seeds. Black and white seeded forms are known not only in cabbage lettuce but also in cos and bunching lettuce. It is very common to find two lettuces almost identical in all respects save seed colour, e.g. *Trocadero* and *Black Seeded Trocadero*, *All the Year Round* and *White Seeded All the Year Round*.

Pigmentation.

All the wild forms of *Lactuca scariola*, and many varieties of cultivated lettuce are characterized by the presence of reddish anthocyanin pigment in epidermal cells of the leaves and petioles. The degree of pigmentation of the leaves varies from complete suffusion of the epidermis, resulting in a dark reddish brown lettuce such as *Continuity*, to a slight tinting of the edge of the leaf as in *May Queen* or *Trocadero*. In some forms, such as *Stanstead Park*, in addition to reddish suffusion of the leaf edges, the leaves have numerous dark purple spots. Many forms that appear only lightly tinted, develop a much more general pigmentation under the influence of adverse growing conditions.

C. E. Durst (3) (1930) has investigated the inheritance of pigmentation in crosses between pigmented and non-pigmented varieties. Using *Big Boston*, *May King* and wild forms of *L. scariola* as tinted parents, and *Grand Rapids* and *Paris White Cos* as untinted parents, he found that, in general, pigmentation behaved as a single dominant factor.

The production of cultivated varieties of lettuce has, in many cases, involved the selection of untinted forms from tinted varieties of lettuce. For instance *Unrivalled* is an untinted selection from *Trocadero*, to which it is in all other respects similar.

Depth of "Greenness" in Leaves.

Varieties are known varying from a light yellowish green (e.g. *Golden Ball*) to a dark green (e.g. *Hardy Hammersmith*). It is possible to arbitrarily arrange lettuces in groups with dark, medium and light green leaves, but it must be realized that in reality these groups are continuous with one another through a series of intermediates. The R.H.S. in their classification (1919) described an even greater number of degrees of "greenness" using such terms as "medium dark green" and "medium light green" in addition to those used above. The weakness of this form of classification is obvious when one has seen the same lettuce growing under different conditions of cultivation.

Little genetical work on the degree of "greenness" of leaves has been carried out. A. H. Bremer (1) found that in a cross between a light lettuce, *Emperor*

Forcing, and a dark variety, *Rudolphs Leibling*, that the dark green type of leaf behaved as a simple dominant factor. Such a result, from a single cross only, cannot be relied upon to be of general application.

Leaf Texture.

Two very distinct types of leaf texture are known. The great majority of cabbage lettuces have leaves of a leathery texture, and when eaten appear to be slightly greasy or "buttery". In America these types of lettuce are called Butterheads. There are also a number of cabbage lettuces with leaves of a crisp or brittle texture, similar to those of cos lettuce. These are more popular in America than England. *Webb's Wonderful* is a typical variety which has been grown to a small extent in England for many years. The crisp lettuces stand hot dry weather without "bolting" much better than Butterheads.

Standing Qualities, i.e. Length of Time for Formation of a Flower Stem.

This is bound up with the season at which varieties of lettuce are usually sown. For example if the varieties *Imperial* and *Unrivalled* were sown in autumn and left to stand the winter they would both form hearts (though *Imperial* being hardier would show a smaller percentage of losses) and would both form a flower stem about the same time the following summer. On the other hand, if both were sown in early summer, *Imperial* would rapidly form a flower stem without previous hearting, whereas *Unrivalled* would take approximately as long to form a flower stem as it does when sown in autumn. This difference has been shown by M. A. H. Tincker (7) to be in fact a difference in reaction to length of day. He showed that lettuces could be divided into two classes, first, those whose pre-flowering period length depends on the length of day, and secondly those in which the formation of the flowering stem does not depend on day length. The members of the first class all formed flower stems more rapidly when, as in summer conditions, the day length was relatively long. In general, one finds that most winter and forcing lettuces belong to the first class, and all summer lettuces to the second.

Genetically, the relation between these two types of day length is rather complex. A. H. Bremer (1), in crosses between *Emperor Forcing* and *Rudolphs Leibling*, found the factor "flower stem dependent on day length" to behave as a simple dominant. Subsequently A. H. Bremer and J. Grana (2) found two other factors that influenced flower stem formation. In crosses between *May King* and *Deacon* some evidence was obtained showing that *May King* carries a shoot formation inhibiting factor, having the same effect under either long day or short day conditions. Also, in their population of *Emperor Forcing*, a supposed mutant arose carrying a dominant factor causing rosette formation as opposed to heart formation.

It is of interest to note that the wild forms of *Lactuca scariola* and *L. virosa* all carry the recessive factor for reaction to day length, that is they are day length neutral.

SHAPE OF FULLY HEARTED LETTUCE.

Shape and appearance of the hearted lettuce, though very difficult to define, appear to be useful means of classifying lettuce varieties. In observations of some two hundred strains and varieties it was seen that certain well-defined groups of lettuce existed, members of each group having similar shaped leaves and a similarly formed heart. On the other hand many lettuces could not be assigned to any particular group. For instance, a large number of forcing lettuces, collectively known in France as Gotte lettuces, have characteristic round leaves, and a circular compact heart. Again, many of our winter lettuces have a typical large heart with loose outer leaves, the leaves being oval and of a rather coarse texture; many of these varieties are known in France as varieties of Passion lettuce.

VALUE OF VARIOUS CHARACTERS FOR CLASSIFICATION.

On the basis of the foregoing analysis of some of the more important characters that might be of use in classification of cabbage lettuces, we can proceed to assess their relative value.

A natural classification should aim at giving some sort of picture of the course of evolution. In the case of a cultivated plant, such as we are dealing with, we have some definite knowledge of the direction that evolution has taken under the influence of artificial selection. The breeder of new varieties selects individuals from a population which are outstanding in one or more desirable qualities, and by further processes of selection a new variety, or at least a new strain, is obtained. Other breeders selecting from a population of the same original variety may produce a slightly different new selection. The result is that groups of varieties and strains exist which are similar in many ways, owing to their common parentage. Some of these groups are well marked, others less so. In so far as these groups do represent the result of the artificially controlled evolution of cabbage lettuces, they must be of fundamental importance in classification.

The accompanying Table (Table I) gives us some idea of the classificatory value of other characters. In this Table is given a list of a number of distinct varieties of cabbage lettuce arranged into their natural groups, with a list of five distinguishing characters for each. In each of these groups we find lettuces with black and with white seeds, pigmented and unpigmented lettuce, and lettuce with various depths of greenness in their leaves. These characters can, therefore, only be used for differentiation of varieties within the groups.

There would appear to have been a good deal of parallel evolution within the groups, particularly in the direction of the development of unpigmented forms.

On the other hand, the character of leaf texture divides cabbage lettuces into two distinct larger groups, and is undoubtedly of major classificatory importance. It will also be seen that, though the correspondence is not absolute, most of the groupings of lettuce in the Table have special cultural uses; for instance those in the first group are all forcing lettuces, those in the third are outdoor winter lettuces, and those in the fifth are summer lettuces. Those in the second and fourth groups, however, have a greater range of cultural uses.

TABLE I.

		Seed Colour.	Pigment.	Leaf Texture.	Depth of Leaf Colour.	Culti- vation.
I.	1. White Seeded Tennisball ..	White	+	Butter	L	F
	2. Gotte à Graine Noire ..	Black	—	"	M	F
	3. Golden Ball ..	White	—	"	L	F
	4. Cheshunt Early Giant ..	White	—	"	M	F
	5. Paris Market Forcing ..	Black	—	"	L	F
	6. Loos Tennisball ..	White	—	"	L	F.W.
II.	7. May Queen ..	White	+	"	M	F.Sp.
	8. Milly Forcing ..	White	+	"	D	F
	9. Majestic ..	White	—	"	M	W.F.
III.	10. Stanstead Park ..	White	+	"	M	W
	11. Wayahead ..	White	+	"	M	W
	12. Passion Blanche à Graine Noire	Black	—	"	D	W
	13. Excelsior ..	White	—	"	M	W
	14. Imperial (Sutton's) ..	White	—	"	M	W
	15. Chavigné ..	White	—	"	M	W
IV.	16. Arctic King ..	White	—	"	L	W
	17. Trocadero ..	White	+	"	M	Sp.W.
	18. Unrivalled ..	White	—	"	L or M	S.Sp.W.
	19. Black Seeded Trocadero ..	Black	+	"	M	S
	20. Improved Trocadero ..	Black	—	"	M	S.W.
V.	21. Webb's Wonderful ..	White	—	Crisp	M	S
	22. Supreme ..	White	+	"	M	S
	23. Ohio ..	White	—	"	M	S
	24. Mignonette ..	Black	+	"	D	S

L=Light Green.

W=Winter.

M=Medium Green.

Sp.=Spring.

D=Dark Green.

S=Summer.

F=Forcing.

Before a final and conclusive classification of lettuces can be arrived at, not only must we have more detailed knowledge of their genetics and cytology, but observations must be made on the growth of many of the less commonly grown lettuces. These would probably in many cases provide links between apparently distinct lettuces grown to-day. The following provisional classification of some of the most commonly grown English lettuces is based on observation

of some two hundred stocks. An important point to be borne in mind is that not only may lettuces of different names be identical or very similar, but that different seedsmen's strains of the same lettuce may be quite appreciably different.

A CLASSIFIED LIST OF CABBAGE LETTUCE VARIETIES GROWN IN ENGLAND.

A. BUTTERHEAD CABBAGE LETTUCES.

I. *Gotte Lettuces.*

The *Gotte* lettuces are mainly used for cultivation under glass, and are much used for this purpose both in England and France. Their distinguishing feature is their rounded leaves, and compact rounded heads. The leaves are usually smooth, not curled or blistered. The lower leaves are not spreading; they are almost "all heart". Black and white seeded, tinted and untinted varieties are found in this group, but all are very similar in form.

WHITE SEEDED TENNISBALL.

White seed, leaves light green, lightly tinged with brown. The leaves are slightly blistered. Very similar varieties are *Boston Market* and *Gotte à Graine Blanche*.

GOLDEN BALL.

White seed, leaves yellowish light green, untinted. Much used for heated greenhouse culture. Synonymous, or very similar, are the varieties *Lemon Queen*, *Buttercup* and *Gotte jaune d'or*.

CHESHUNT EARLY GIANT.

White seed, leaves medium green. A selection from *Golden Ball*, to which it is similar in appearance in all respects save colour. Hearts particularly rapidly in greenhouses in mid-winter.

BLACK SEED TENNISBALL.

Black seed, leaves medium green untinted. Suitable for culture under cloches or cold frames. Synonyms are *Salamander* and *Gotte à Graine Noire*.

PARIS MARKET FORCING.

Black seed, leaves light green, slightly tinted, very similar in appearance to *Golden Ball*. Rather susceptible to downy mildew. Similar varieties are *Sutton's Early Paris*, *Central Market Forcing*, *Gotte à Forcer*, and *Gotte à Chassis à Graine Noire*.

EARLY FRENCH FRAME.

Black seed, leaves medium green, untinted. A smaller lettuce, very quickly maturing. Susceptible to downy mildew, though resistant strains are now available. The same lettuce as *Gotte à Couches à Graine Noire*.

LOOS TENNISBALL.

White seed, leaves a bright light green. This is a larger lettuce than *White Tennisball* and the leaves are much smoother. Much used for frame and heated greenhouse culture; it is quite hardy and will stand the winter out of doors. Very resistant to mildew. Synonym—*Gotte à Graine Blanche de Loos*.

II. All the Year Round Lettuces.

These lettuces, as their name implies, are suitable for cultivation at all seasons. They are considerably used for spring and summer outdoor sowing, and to a smaller extent for standing the winter. For this last purpose a more hardy lettuce is required in all but the mildest districts. These lettuces are undoubtedly related to the *Gotte* lettuces, particularly to *Gotte à Graine Noire*, both in the roundness of the leaf and in the general shape of the matured lettuce. No tinted forms are known.

ALL THE YEAR ROUND.

Black seed, leaves medium green. A fairly large lettuce with smooth leaves forming a large firm heart. Varieties differing only in size, or in the time taken to mature are *Matchless*, *Yates' Double Six*, *Excellent*, *Long Stander*, *Dryweather* and *All the Year Round Improved*.

SUTTON'S SPRING BEAUTY.

White seed, leaves round, medium to dark green. This lettuce is quite hardy and suitable for sowing at all seasons. Sown in the autumn it takes longer to mature than some of the standard winter varieties and forms a useful succession. Probably this variety is similar to the old *White Seeded All the Year Round*.

FELTHAM KING.

White seed, similar to *Spring Beauty* but not so hardy. Sometimes grown under glass, but very susceptible to mildew. The same as *Gloire de Nantes*.

III. *May Queen Lettuces.*

This group of lettuces is composed mainly of those used for cold frame and outdoor culture in spring. Some are sufficiently hardy to stand the winter. In appearance these lettuces bear some similarity to the Gotte lettuces, particularly *Gotte à Graine Blanche*, but the leaves are more blistered and crumpled, and the hearts less firm. Most, but not all, have a slight reddish tinge particularly near the leaf edges. The leaf texture is very delicate and the hearts very tender. These lettuces are very early and are highly resistant to mildew.

MILLY.

White seed, leaves medium green, deeply tinted with reddish pigment. Forms a compact, white heart. Not much grown in England now, but used to be grown extensively in frames, and in spring and summer out of doors. Identical forms are *Grand Admiral*, *Cordon Rouge*, *Red Edged Victoria*.

HÂTIVE DE MILLY.

White seed, leaves less suffused with red than *Milly*.

MILLY FORCING.

White seed, leaves dark green tinged reddish brown at edges. This is a very early lettuce much used for cold frames. Other names are *Hothouse* and *A Forcer de Milly*. Similar varieties, but lighter in colour and more rapidly maturing are *Premice* and *Rosy Spring*.

EARLY PARIS MARKET.

White seed, leaves medium green, slightly tinted with red. The leaves are slightly blistered. This is a small lettuce much used for forcing in frames. This is the same as *Crêpe à Graine Blanche* and *Laitue George*. *Evergreen* is a darker green, untinted selection.

MAY QUEEN.

White seed, leaves medium green, lightly tinted with red. This is a large lettuce forming large hearts. It is used for culture in heated houses, and for sowing in autumn to stand the winter, but its main use is in frames and for spring outdoor sowings. Similar varieties are *May King*, *May Duke* and *Reine de Mai*.

A number of untinted selections from *May Queen* have been produced having similar uses. These include such forms as *Earliest Springtide*, *Queen of the May*, *Giant May* and *Victor Forcing*.

Other untinted selections, both much larger and much hardier than *May Queen* are *Winter Victor* and *Majestic*.

IV. *Trocadero Lettuces.*

Trocadero lettuces are extensively used for outdoor sowing at all times of the year. They mature rapidly and stand hot weather well, and so are very considerably used in this country for growing in spring and summer. *Big Boston*, a variety in this group, is the most extensively grown lettuce in the United States. The characteristic features of lettuces in this group are the tendency for the outer leaves to fold longitudinally and the narrowness of the leaf at the lower end where it joins the petiole. Consequently these lettuces have not the compact roundness of the Gotte lettuces and the other groups so far considered. The petiole, also, is rather larger in proportion to the leaf than in other Butterhead cabbage lettuces. In general appearance all members of the group are very similar, differing mainly in size, earliness and degree of anthocyanin pigmentation.

TROCADERO.

White seed, leaves medium green, tinted with reddish brown near the edges. Leaves much blistered and folded. Other varieties differing only in size and time taken to reach maturity are *Big Boston*, *Paragon*, *Ideal* and *Lorthois à Graine Blanche*.

UNRIVALLED.

An untinted selection from Trocadero. The leaves are a light green. There are a large number of very similar varieties differing only in minor points as depth of greenness. These include *White Big Boston*, *Big Boston Improved*, *Green Trocadero*, *Improved Unrivalled*, *Borough Wonder*, *Britannic*, *May Wonder* and *Market Favourite*.

BLACK SEEDED TROCADERO.

Black seed, otherwise similar to *Trocadero*. Some strains of this variety are untinted, others are tinted. Used for spring and summer sowing only. Synonymous with this variety are *Black Seed Big Boston*, *Lorthois à Graine Noire* and *Perpignan*.

IMPROVED TROCADERO.

Black seed, similar in appearance to *Unrivalled*.

V. *Lee's Immense Lettuces.*

These varieties are used only for sowing out of doors to stand the winter. When sown in summer they bolt rapidly. Some of these varieties have been grown in England for over a hundred years. They are of medium or small

size, and have medium or dark green leaves of very coarse texture, rather bitter to taste. The leaf surface is rather dull in appearance and unblistered. The edges of the leaves are very little folded and have a characteristic yellowish colour.

LEE'S IMMENSE.

White seed. Some strains have dark green leaves, others are considerably lighter. Synonymous or very similar varieties are *Clarke's Imperial*, *Harrison's Green Winter*, *Yates' Winter White* and *Schofield's Hardy Winter White*.

HARDY HAMMERSMITH.

Similar to *Lee's Immense* but of a very dark green colour and bitter flavour. Though very hardy it is not much grown nowadays because of its coarse appearance and taste. Similar varieties are *Hammersmith* and *Webb's Immense Hardy Green*.

VI. *Passion Lettuces.*

These lettuces are all very hardy and almost exclusively used for autumn sowing to stand the winter out of doors. They bolt without forming a heart if sown in summer. Most of them are large lettuces with coarse fleshy leaves. Some are tinted; these, in addition to the reddish brown suffusion of the edges of the leaves, have characteristic dark purplish brown spots all over the leaf surface.

STANSTEAD PARK.

White seed, leaves medium green with reddish tinting and purple spots. This is a large lettuce with a large firm heart. *Green Winter Passion*, *Passion de Château Renard*, *Standard Winter*, *Improved Winter*, *Tremont Winter* and *Sutton's Early Spring* are closely related varieties.

WAYAHEAD.

White seed, leaves paler green than *Stanstead Park*, though similarly tinted. This is a medium sized lettuce formerly extensively grown in U.S.A. and still considerably used in France under the name *Passion d'Hiver Blonde*.

BLACK SEED WINTER PASSION.

Black seed, leaves large of medium green colour, untinted.

SUTTON'S IMPERIAL.

White seed, a light green lettuce with a very light undersurface to the leaves. This hearts well and early and appears much less coarse than most members of this group.

WINTER PASSION EXCELSIOR.

A German variety very similar in appearance to *Black Seed Winter Passion*, but with white seed. *Harrison's Excelsior* is a very similar lettuce.

WHITE CHAVIGNÉ.

Is a medium sized lettuce similar to *Excelsior*, said to be a selection of *Green Winter Passion*.

ARCTIC KING.

White seed, is a small lettuce, pale green and tender. It is very hardy and hearts early. Though rather distinct in appearance from all the *Passion* lettuces, this variety is probably closely related. *Arctic* and *Blatchford's Winter Monarch* are similar.

VII. *MacHattie's Giant Lettuces.*

MACHATTIE'S GIANT.

White seed, very large pale or medium green leaves, much blistered. The lower leaves are large and spreading, the heart round and rather loose. Used mainly for autumn sowing, this lettuce is similar in many respects to the *Passion* lettuces, but not so compact. Similar varieties are *Goliath*, *Whitsuntide*, *Bourguignonne* and *Large White Winter*.

B. CRISP HEARTING CABBAGE LETTUCES.

VIII. *Iceberg Lettuces.*

These crisp hearting lettuces are very little grown in England, though very popular in America. They are very suitable for growth in summer as they stand for a long time before running to seed. In all forms the leaf edges are more or less frilled and in some cases fringed like curled *Endive*. The leaves are usually much blistered.

ICEBERG.

White seed, leaves medium green tinted with red at the margins. Very large lettuce, but with a compact heart. Leaves blistered, but leaf edges not much frilled. *Royal Albert*, *Supreme* and *Crystal Palace* are similar varieties.

WEBB'S WONDERFUL.

White seed, leaves medium green, untinted. Leaf margins undulate. A medium sized lettuce forming a crisp and firm heart. Similar varieties are *New York*, *Duke of Cornwall*, *A.I.*, *Hercules* and *Jagger's Imperial*.

MALTA or DRUMHEAD.

White seed, leaves medium or pale green. A very large lettuce with a large loose heart.

OHIO.

White seed, leaves light green with much fringed edges. Stands a long time before running to seed. *Denver Market*, *Favourite* (Sutton) and *Perpetual* are similar varieties.

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STUDIES IN BIENNIAL BEARING.—I

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East Malling Research Station

INTRODUCTION.

THIS is intended to be the first of a series of papers on various aspects of biennial bearing. Many apple trees in the East Malling Research Station plantations have for several years been markedly biennial in habit. Records of the number and weight of fruit borne by each tree, normally collected each year, and in several cases records of fruit buds, provide a considerable quantity of data on the prevalence of the habit, and the influence on it of numerous experimental treatments applied for various purposes. In 1930, also, certain trials were begun of methods designed expressly to show whether and to what extent the habit can be controlled. The first necessity was clearly a method of showing whether any particular tree was regular, biennial, or irregular in habit, and the intensity of the habit when present. The method here employed is explained in Part I. Part II deals with the effects of various treatments in the experimental plantations and Part III with certain attempts at control.

As the method of study, so far as the authors are aware, is new, few references to previous work on the subject are made. Readers may be referred to a forthcoming Occasional Paper of the Imperial Bureau of Fruit Production, entitled "Annotated Bibliography on Biennial Bearing."

PART I. TECHNIQUE.

In making a study of biennial bearing it is useful to have a method of estimating to what extent a tree is bearing regularly every year, irregularly or is systematically biennial. It is easy to show in a diagram the history of a single tree or the mean of a number of trees; but if it is desired to test whether that mean represents the performance of the trees which contribute to it, or whether it differs from that of another set of trees, it is necessary to translate comparative cropping from year to year into figures.

There are two distinct aspects of the biennial habit in blossoming or fruit which must be considered in making a numerical estimate of its extent. First it is necessary to determine whether the tree is a victim of the habit wholly, not at all, or for certain periods only. Secondly the violence with which the crops fluctuate must also be estimated.

Fig. 1(a) shows the cropping history of one unpruned tree of Early Victoria from 1923 to 1934. In this case, in number of fruits the tree is definitely

biennial over the whole period, i.e. every heavy crop is followed by a lighter one and vice versa. If this alone were taken into account, there would be no difference between this tree and that described in Fig. 1(b) as regards the biennial habit. Actually, however, the two are very different; for while the fluctuations in the first case are, with one exception, from a crop to practically nothing, in the second the "off" years are generally nearly as heavy as the "on" years, taking into consideration the gradual increase in the capacity of the tree.

In making a numerical estimate, both factors must be taken into consideration and it is necessary to evaluate the two separately. The first is measured by the figure which is here called "B". This figure can vary from one hundred, when the biennial habit is complete as in Figs. 1(a) and (b), to zero, which would mean a gradual rise or fall over the whole period or equality throughout. Fig. 1(c) shows a case where "B" gives an intermediate value. The crops were irregular until 1930, but became markedly biennial from then on. Fig. 1(d) shows a tree where there is only one fall (1930) and "B" must be very low.

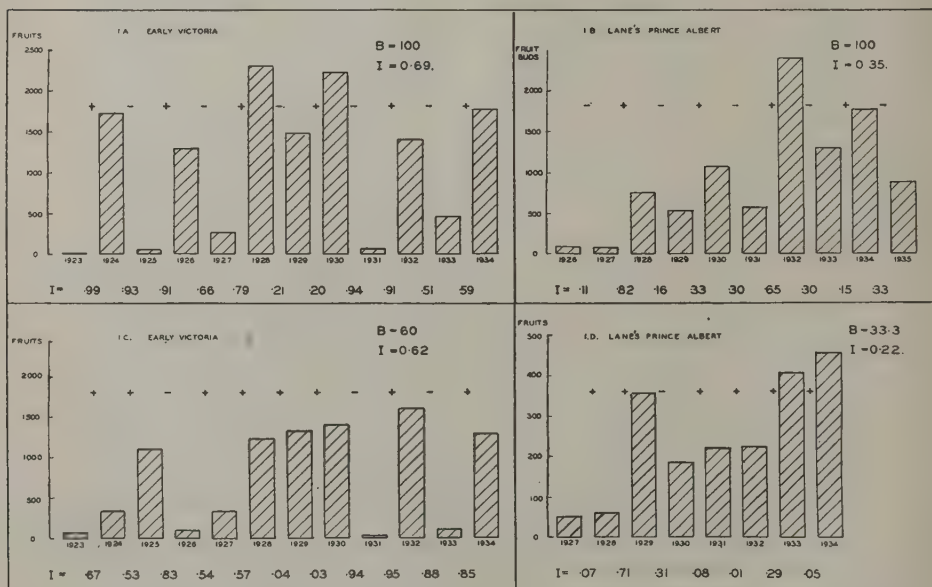


FIG. 1.

Annual Crops of Fruit or Blossom of four trees selected to illustrate different degrees of regularity of bearing and intensity of fluctuation.

It is possible to find cases where "B" = 0, but seldom over more than a short period.

The evaluation of "B" is very easy. It takes at least three years to determine whether there is any sign of biennial bearing or not. If the tree is biennial the differences between consecutive pairs of years will be unlike in sign, i.e. - + or + -. If not, they will be alike, either + + or - -. "B" is determined from the number of pairs of unlike signs over the whole period. Thus in Fig. 1(a) there are ten possible pairs and all ten are unlike, i.e. 100 per cent. and "B" is said to be 100. In Fig. 1(b) "B" is the same; in Fig. 1(c), however, there are only 6 out of 10 pairs of unlike signs (+ + - + + + - + - +), and "B" is only 60. Actually the tree has only become regularly biennial during the last four years. In Fig. 1(d) there are only 2 pairs out of a possible 6 or 33·3 per cent. and "B" is thus 33·3.

It is evident that "B" gives but a rough idea of the degree to which the tree has acquired the biennial habit, and it is now necessary to supplement it by some measure of intensity. In the extreme case a tree will only bear fruit in alternate years; and irrespective of the size of the crop in the "on" year, if there is nothing in the "off" year the intensity must be high. At the other end of the scale the crops in succeeding years may be equal and in this case the intensity must be zero. The simplest method of measuring these fluctuations is to divide the difference between each consecutive pair of years by their sum. If this is done, the Intensity ("I") will vary from 0 to 1, where 0 denotes equal crops and 1, no crop at all in the "off" year.

Few trees show the biennial habit in its most intense form consistently over a long period—even when "B" = 100. It is more usual for the intensity to vary, seasonal and cultural conditions often influencing it to a considerable extent. Again, even regular cropping varieties usually have an occasional "off" year. A study of the changes in intensity over the whole period is thus an essential part of any such investigation.

Referring back to Fig. 1(a), the first four seasons (1923-26) show two "on" years in which there were comparatively heavy crops and two "off" years in which the failure was almost complete. These yield three pairs, the intensity figures for which are ·99, ·93 and ·91. The difference between 1926 and 1927 is not so great, there being a small crop in 1927, and "I" drops to ·66; but the biggest crop to date, in 1928, increases the intensity for 1927-28 to ·79. The years 1928, 1929 and 1930 all produced heavy crops, the "off" year (1929) being only slightly less than the other two, and "I" falls to ·21 and ·20; but an almost complete failure in 1931 raises the next two pairs to ·94 and ·91. After this the intensity falls again to ·51 and ·59 for the next three years, since a moderate crop was harvested in the next "off" year (1933). If it is desired to compare this tree with another tree for which "B"

is the same or nearly the same, but whose fluctuations are more or less intense, these intensities may be averaged and a single figure for "I" obtained, which will represent the fluctuations over the whole period. In this case the average "I" = .69.

It should be emphasized, however, that it is comparatively seldom that this average is sufficient to describe the behaviour of the tree, the changes in intensity being generally of much greater interest.

Fig. 1(b) shows a hundred per cent. biennial tree of quite a different type. The fluctuations here are of a much lesser order, and the only two of any size (1927-28 and 1931-32) are much more likely to be associated with the coming into bearing of the tree and increase in bearing capacity, than with the biennial habit. Even including these two high pairs the average intensity of the nine pairs of years is only .35, which shows that though the biennial habit is certainly there, it is as yet of little importance.

Fig. 1(c) represents a tree with a low value for "B", and a case in which an examination of the changes in intensity only can give a real picture of the tree's history. In the first three years the tree is coming into bearing, giving a gradual increase in crop, and it would probably be better to omit the two years prior to 1925 from the study. After the heavy crop of 1925, however, there is a very low crop in 1926 followed by a moderate crop in 1927. This is reflected in the intensity figures .83 and .54. The next three crops are all high and in the years 1928-29 and 1929-30 the intensity drops to almost zero. Following this period, however, the tree becomes as violently biennial as that in Fig. 1(a) and the intensity rises accordingly. The mean for the whole period is .62.

It may be noted that by this method, where both crops are comparatively high, the actual difference may be much greater than where both crops are low, and still give nearly the same intensity value as in the years 1926-27 and 1927-28 for this tree.

Finally, Fig. 1(d) shows a tree for which both "B" and "I" are very low. Here there is as yet no real sign of the biennial habit. With the exception of the years 1928-29 there is no value of "I" of any size. The exceptionally heavy crop in 1929 was probably due to some external factor; and since it was not followed by a complete failure in 1930, as is so often the case with some varieties, it cannot be attributed to the biennial habit. The mean value of "I" is here .22.

The work of evaluating these intensity values is rather laborious, when it has to be done for a large number of trees over a long period. In certain cases it may be to some extent curtailed by omitting intermediate pairs of years (e.g. evaluating 1928-29, 1930-31, 1932-33 and omitting 1929-30 and 1931-32).

This can generally be done with safety when "B" is high. It should be emphasized, however, that care must be taken in selecting the starting point. As a rule a start should be made with a year in which there is a heavy crop ; if this is not done the average value for "I" may be greatly exaggerated, especially where the tree has not yet attained its maximum cropping capacity. Thus in the example Fig. 1(b), had a start been made in 1927, the four consecutive pairs omitting intermediates would give "I" = .47, whereas starting in 1928, "I" would be .27 which value probably gives a much truer picture of the fluctuations in this tree.

THE MEASURE OF FRUITFULNESS.

Having decided upon a method of evaluating the biennial habit, it is necessary to decide on a measure of yield. From the point of view of the grower the weight of fruit harvested is probably all that matters ; but in investigating causes and effects, the components which go to make up this final yield must also be considered. For that reason in this paper number of fruits including windfalls will be considered in preference to crop weight. However, even this is often not sufficient to show the biennial tendency. As will be shown later, it generally happens that in a heavy blossoming year a low proportion of the flowers set fruit, and vice versa. Thus in a hundred per cent. biennial tree the intensity for fruiting is usually lower than that for blossoming. In more complicated cases other factors, e.g. the weather, combine to influence the proportion of fruit which set. Thus, unless the intensity of fluctuation for blossoming is very high, it may happen that the habit of the tree as shown in its flowering is hardly reflected at all in the fruit.

Fig. 2 shows the average cropping history of three sets of twenty trees each of Lane's Prince Albert on three rootstocks as shown by amount of blossom and number of fruits. These trees form part of the apple rootstock trials at this Station and were sixteen years old at the end of 1934. They are perhaps not ideal for the purpose, since Lane's Prince Albert is not usually a biennial variety ; but they do illustrate how little correlation there may be between blossom and fruit. In two out of the three sets (Nos. IX and XVI) shown in the diagram, significantly higher values for "B" are found for fruit buds (counted after pruning) than for fruit.

The fluctuations in intensity are shown in graphical form in Fig. 3. It should here be pointed out that among these trees there is considerable tree to tree variation ; so that the average intensities do not always correspond very closely with the fluctuations in average yield shown in Fig. 2. Thus, while broad differences are clearly shown, the apparent equality in blossom formation of the trees on No. I (for example) from 1931-34 is not altogether reflected in the average intensities, although these are indeed low.

The differences between fruit bud formation and eventual crop are clearly shown in Fig. 2, and the effect upon the intensity figures in Fig. 3. These are evidently the result of big differences in fruit set. Thus with the trees on No. I, very even blossoming in the last four years is not reflected in regular fruiting. On No. IX, although there is a distinct biennial tendency in fruit-bud

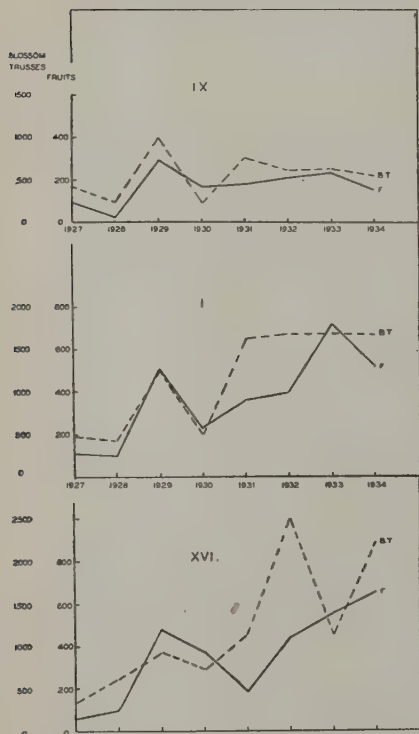


FIG. 2.

Average Annual Fruit Bud Formation and Number of Fruits of twenty trees of Lane's Prince Albert on three clonal rootstocks from the Ninth to Sixteenth Year.

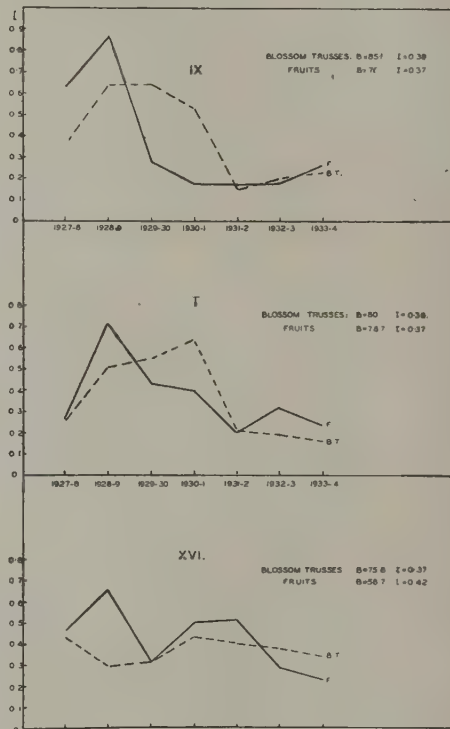


FIG. 3.

Average Biennial Intensity of Fluctuation in number of Blossom Trusses and Fruits of Lane's Prince Albert on three clonal rootstocks from the Ninth to the Sixteenth Year.

formation from 1927-31, after the first three years this is hardly distinguishable in the fruit. Finally, on No. XVI, there is but little connection between blossom and fruit, especially during the last four years—the differences in blossom set being very marked.

In all three cases there is comparatively little difference between the average intensities for the period, and this serves further to illustrate their limitations.

It seems clear, therefore, that in any piece of research upon habit of bearing, a study of the blossoming is essential.

PART II. OBSERVATIONS ON THE APPLE PRUNING PLOT.

(i.) HISTORICAL.

The Apple Pruning Plot comprises the oldest trees at the Research Station ; part of it was planted with yearlings in the winter of 1913-14, and the remainder a year later. Although little information is available before 1919, the crop records of these trees cover a longer unbroken period than those of any other trees in the Research Station plantations. A few trees carried a heavy crop (for their size) in 1919, and a much lighter crop in 1920 ; the biennial habit was thus beginning to appear as early as the seventh and eighth year from the bud. Since that time many trees have shown the habit very clearly ; rather few, however, have been completely regular in their alternation of heavier and lighter crops.

(ii.) TREATMENTS AND RECORDS.

The Apple Pruning Plot consisted (until the end of 1934) of twenty sets of trees comprising fifteen varieties, five varieties being in duplicate on commercial " crab " and " paradise " stocks. Four pruning treatments, two involving leader tipping and two not, have been compared on each set ; the unit of trees for each pruning treatment is eight. This unit was subdivided early in 1923 in order to superimpose a potash manuring trial, of which details are given below.

In the spring of 1932 a few sets of trees were again subdivided for the purpose of testing certain supplementary pruning treatments, such as spur shortening and " dehorning ".

In April 1930, also, the older part of the plot was seeded down with grass ; since then it has been under continuous " sod mulch " treatment, with dressings of nitro-chalk from 1932 onwards.

There are on the Apple Pruning Plot, therefore, in addition to a comparison of fifteen varieties, a number of treatments which may have affected either the regularity of bearing, or the intensity of the biennial (or irregular) habit.

The available records, of use for the present purpose, consist only of the number and weight of fruit borne by each tree each year. Partial records of the number of fruit buds were taken in the years 1919 to 1925 ; but since few

trees had the biennial habit strongly established before 1923, these records are not of much value here. With one exception, which will be pointed out, the data and discussion which follow are based entirely on *number of fruits* (wind-falls above a certain minimum size are included); total weight of crop and fruit size are not here considered. The figures for the intensity of the biennial habit here used are higher than they would have been if calculated from weight of crop; for the fruit of the "on" year is almost invariably smaller than that of the "off" year, and the crop weight is therefore less unequal from year to year than the number of fruits.

(iii.) STARTING POINT.

For the present purpose a common starting point for all sets of trees to be compared is obviously essential. At the same time, no one starting point can be completely satisfactory. Different varieties differ very much in the age at which they show the first signs of the biennial habit; and leader tipping, by delaying the bearing of nearly all the trees subjected to it, may also delay the development of the habit. A compromise has been chosen, by taking throughout the crops of the twelve-year period, 1923-34 inclusive. (The crop of 1935 was negligible owing to the spring frost.) For calculating "B", this gives ten pairs of signs, like or unlike. It is true that in a few cases, especially of the leader-tipped trees of the slower bearing varieties, crops were steadily increasing until after 1923. In such cases the figure for "B" should presumably be slightly higher than that shown. But that this has not greatly affected results may be judged by the fairly low figure for "B" of a quick cropping variety, James Grieve, and the higher figure for a much slower cropping variety, Newton Wonder. Again, the leader-tipped trees of Norfolk Beauty, where the delay in cropping due to tipping was extreme, have a higher figure for "B" than the comparable untipped trees.

It is thought, therefore, that the choice of 1923 as a common starting point is not likely to give any seriously misleading results.

(iv.) COMPARISON OF VARIETIES.

It has long been realized that varieties differ widely in their tendency to develop the biennial habit, and in the degree to which they develop it. Worcester Pearmain and James Grieve have a high reputation as amongst the most regular bearers; whilst Bramley's Seedling (not, unfortunately, included in the Pruning Plot) and Early Victoria are widely recognized as strongly biennial varieties. In the third place, Cox's Orange, and to a less extent, Lane's Prince Albert, have been regarded as irregular in bearing rather than strictly biennial.

Examination of the records by the method described in Part I bears out in the main these preconceived ideas. The figures are given in Table 1.

Worcester Pearmain and James Grieve (except the trees of the latter on "Paradise", now known to be mainly No. V) are amongst the lowest of the fifteen varieties in both "B" and intensity. Beauty of Bath is also rather low in both. Newton Wonder, Gladstone, Early Victoria and Allington are all high in both respects. Cox's Orange is very low in "B", and about medium in intensity; this clearly suggests that the current view is correct, since it must indicate irregular rather than biennial bearing. Norfolk Beauty is similar to Cox's Orange; Lane's Prince Albert, however, is not, but is a little below the general mean in both "B" and intensity.

TABLE I.
Biennial Bearing, Comparison of Varieties.
Period 1923-34 inclusive.

Variety.	Commercial Stock.	Age, end of 1923, years from bud.	"B."	Intensity.
Allington	"Paradise"	11	80	·60
Annie Elizabeth ..	"Paradise"	9	75	·41
Beauty of Bath ..	"Paradise"	11	62	·41
Bismarck	"Crab"	10	77	·60
Cox's Orange	"Paradise"	10	62	·45
Early Victoria ..	"Crab"	10	78	·56
Early Victoria ..	"Paradise"	10	90	·70
Gladstone	"Crab"	10	82	·59
Gladstone	"Paradise"	10	91	·63
Grenadier	"Crab"	11	83	·48
Grenadier	"Paradise"	11	72	·49
James Grieve	"Crab"	10	61	·26
James Grieve	"Paradise"	10	74	·34
Lane's Prince Albert ..	"Crab"	11	73	·42
Lord Derby	"Paradise"	10	74	·45
Newton Wonder ..	"Paradise"	11	82	·71
Norfolk Beauty ..	"Paradise"	10	63	·47
Rival	"Paradise"	10	74	·44
Worcester Pearmain ..	"Crab"	11	63	·26
Worcester Pearmain ..	"Paradise"	11	68	·31
General Mean			74·3	·48

Whilst this relative behaviour of the varieties concerned, based as it is on a twelve-year crop record, may be taken as in the main typical of their behaviour in the East Malling soil, it is not suggested that there will never be exceptions, even in what appear to be very similar conditions. Under widely different conditions some of the varieties may, and often do, behave very differently. Even Newton Wonder, Early Victoria and Bramley's are sometimes known to crop regularly over a considerable period; and varieties which have been fairly regular at East Malling are sometimes noticeably biennial in habit.

(v.) EFFECT OF SOIL AND POSITION.

Whilst the soil of the plot is, on the whole, fairly uniform, it is known that there is some variation in its depth. The current idea that manuring or other soil treatments may influence regularity of bearing receives a measure of support from the influence of grassing-down (see (viii.) below): but the known soil variations in the plot do not appear to have been consistently associated with differences or fluctuations in biennial bearing.

It has often been observed that headland trees are apt to behave differently from others in growth and cropping; where leaf-scorch is present, headland trees are usually less affected than others. Comparisons of the records of the trees on the three available headlands with those of the most nearly comparable trees shows that the headland trees have, on each headland separately, a somewhat higher mean "B" figure than the comparable trees. Their biennial intensity, however, does not seem to have been consistently affected, except where another factor enters.

On the north side, the headland trees stand at a distance varying from eight to eighteen feet from a poplar windbreak. For a number of years the growth and cropping of these trees has been relatively poor, presumably owing to the competition of the poplar roots. Their biennial intensity is in the great majority of cases distinctly higher than that of comparable trees. It seems very probable that root competition is responsible.

(vi.) EFFECT OF PRUNING.

Of the four pruning treatments, two involved leader-tipping and two did not. The most obvious pruning effects in the trial have always been those caused by leader-tipping; it is therefore considered legitimate, in discussing the effect of leader-tipping, to compare the mean of the two units whose leaders were tipped with that of the two whose leaders were not tipped.

(a) *Leader-tipping.*

It must be remembered that with few exceptions the leader-tipped trees of any one set were treated identically each year, from early in the experiment until the present time. The severity of the tipping was not varied from year to year to suit the condition of the tree, according as it was weak or vigorous, or was in its "on" or "off" year. Consequently there is no obvious reason, except the delay in cropping caused by leader-tipping, why the biennial habit should be affected.

Examination of the records does not show any consistent effect of leader-tipping. In a few cases the onset of the biennial habit is clearly delayed; in others there does not seem to be any noticeable delay. The intensity of the habit shown by the tipped trees is in a few cases much higher throughout the

whole or a large part of the period ; but in others it is quite as much lower, and in the majority of cases it differs little from that of the untipped trees.

The only possible deduction is that, if the leader-tipping has affected biennial intensity at all (beyond the few cases of delay already mentioned), it has affected some varieties in one direction and others in the opposite direction. Whilst a similar deduction is drawn below from the effects of potash manuring, this is in several cases supported by effects of changes in treatment to which the trees were subjected. In the present case there was generally no change in treatment, except the pruning of the formerly "unpruned" trees in 1929, which is referred to below. There seem to be no grounds for concluding that leader-tipping has, beyond the delay mentioned above, appreciably affected either regularity of bearing or the intensity of the biennial habit.

(b) *"Regulating", and the Pruning of formerly "Unpruned" trees.*

Up to 1929 the "regulated" trees in the pruning plot were most nearly comparable in treatment with the entirely "unpruned" trees ; their leaders are not tipped, the heads being merely kept moderately open. This involves with most varieties no more than a light annual pruning. Since uniform annual leader-tipping has had no consistent effect on the biennial habit, it seems hardly likely that "regulating" will have had such an effect. Actually, no such effect can be traced from the records.

At the end of 1929, however, the formerly "unpruned" trees were heavily thinned out ; subsequently they were pruned annually, in most cases with more or less leader-tipping. Since that time, the behaviour of the formerly "unpruned" and the "regulated" trees has been somewhat different, especially in their biennial intensity.

The difference at first varied in different cases. Since the first effect of the severe pruning of the "unpruned" trees was usually a reduction in crop, it was to be expected that the intensity of the biennial habit would at first be increased or reduced according as the majority of the trees had an "on" or "off" year immediately prior to the pruning. This was found to be the case. Out of 20 available comparisons, the intensity of the habit shown by the "unpruned" trees (as compared with the "regulated") rose immediately after the pruning in 11 cases and fell in 9 ; in nearly every case the connection of the rise or fall with previous cropping could be traced.

After one or two years, the crops of the formerly "unpruned" trees again increased, and in several cases reached the mean weight (though not the mean number, since the fruit was larger) of the two years prior to the pruning. At this stage the biennial intensity was usually reduced ; of the 20 comparisons, 16 showed a definite reduction and only 4 an increase. It seems, then, very probable that one of the eventual effects of the pruning of the "unpruned"

trees was a tendency to even up cropping, and this regardless of the immediate difference due to the effect of pruning in the "on" and "off" years.

(c) *Pruning Treatments Differing in the "on" and "off" years.*

There has for several years been some disagreement regarding the probable effect on the biennial habit of pruning differently in the "on" and "off" years (or of omitting pruning in one of them); and those who expect to get a reduction in biennial intensity from such differences in pruning also disagree as to the choice of the "on" or "off" year for the work. The "off-year-pruners" suggest that the aim should be to encourage longer growths in the "off" year, and thereby to reduce the formation of fruit buds in that year. To the "on-year-pruners" it seems more natural to suppose that the removal of many fruit buds long before the blossoms open will allow the differentiation of more fruit buds, to fruit in the following "off" year. With this in view, it was decided early in 1932 to observe the actual effects of such treatments on certain trees of Allington and Lord Derby.

The sixteen leader-tipped trees of Allington used for this purpose had, for a number of years, shown a highly biennial habit; their "B" figure approached 100 per cent., and their intensity was at that time as high as that of any trees in the Pruning Plot. Further, they were all "in step", having all cropped heavily in 1927, 1929 and 1931, and extremely lightly in the intermediate years. All the trees were very well furnished with long and much branched spurs, which in the "on" years each produced many trusses of blossom.

Half the trees had their spurs severely shortened early in 1932; and the other half were similarly treated a year later. Since 1932 was the "off" year, the former will be referred to as "off-year-pruned", and the latter as "on-year-pruned". Each set of trees was again spur-shortened two years after the first shortening; but the treatment was of necessity much less drastic, owing to the large amount cut away at the first spur-shortening.

The twenty-eight trees of Lord Derby had a "B" figure close to the general mean for all varieties, and a moderate biennial intensity (see Table I). They were nearly all "in step", having cropped more heavily in the same years as the Allingtons, 1927, 1929 and 1931; the few exceptions were more irregular than biennial.

Half the trees were "dehorned"—cut back into ten or twelve-year-old wood—early in 1932, and the remainder early in 1933. As this treatment could not be repeated, the subsequent pruning was practically uniform from year to year—thinning out with fairly severe leader-tipping.

The interpretation of the results obtained from these trees is by no means simple. As was remarked above, any treatment which reduces the crop

immediately, if applied early in the "off" year, will apparently increase the biennial intensity, whilst if applied early in the "on" year, it will reduce it. In the case of the Allington trees, however, the "off" year crops were already so small that there was little room for further reduction, and even a reduction in the "on" year crop could not immediately reduce the intensity materially; nothing could much affect the intensity except an increase in the "off" year crops. If the immediate reduction of the "on" year crop due to "on-year-pruning" were followed by an increased "off" year crop, *then* the intensity would be reduced; the effect, however, could not be called "immediate".

Unfortunately, available records are not complete enough to show in one graph the exact course of events. Up to 1934 the fruit record is complete; but the spring frost of 1935 prevented cropping in that year. Since the "on-year-pruning" was only begun in 1933, fruit records to 1934 are hardly enough to give a complete picture. Blossom records are available for 1934 and 1935, but are unfortunately incomplete for 1933. It becomes necessary, therefore, to supplement the fruit record up to 1934 with the 1934 and 1935 blossom records.

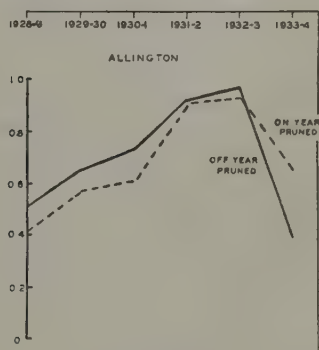


FIG. 4(a).

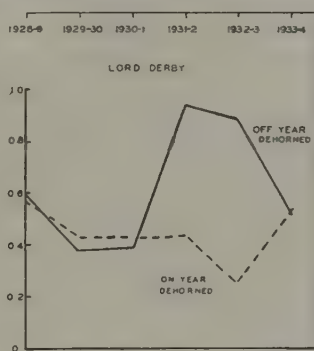


FIG. 4(b).

Biennial Intensity—Effects of "on-year" and "off-year" pruning and dehorning.

Fig. 4(a) shows the fluctuation of the biennial intensity for the two sets of trees, based on number of fruits for the period 1929-30 to 1933-34; and Table II shows the mean number of fruit buds per tree for 1934 and 1935, and the biennial intensity calculated therefrom.

The graph shows that, up to 1932-33, the biennial intensity of both sets of trees was rising; there was then a sharp fall, the intensity of the "off-year-pruned" trees falling much more steeply than that of the "on-year-pruned" trees, with the result that the curves cross for the first time. Table II, supplementing the story by means of the fruit bud records, shows that the same tendency was continued. A difference in intensity between .57 and .90 is very

large, and may be regarded as strongly reinforcing the result shown by the graph. It appears more emphatic if expressed in the form of the proportion of 1934 fruit buds to 1935 fruit buds; this, for the "off-year-pruned" trees is 1:3.7, and for the "on-year-pruned" trees 1:19.8.*

There is here, then, a fairly definite result showing a much greater reduction in intensity following "off-year" than "on-year" pruning. The result of the very different treatment of the Lord Derby trees is much less definite, but at least not contradictory.

TABLE II.
Biennial Intensity—Allington.
Mean number of Fruit Buds per tree.

	1934.	1935.	Intensity.
"Off-year-pruned"	452	1,653	.57
"On-year-pruned"	159	3,140	.90

These trees had borne at least a moderate amount of fruit in their "off" years. Since the immediate effect of the "dehorning" was a reduction in crop, the "off-year-dehorning" inevitably at first increased biennial intensity, and "on-year-dehorning" inevitably reduced it. This is shown in Fig. 4(b). Subsequently, the relative behaviour of the two sets of trees appears to be similar to that of the Allington trees; the intensity of the "off-year-dehorned" trees falls sharply, whilst that of the others rises quite as sharply. Since, however, the relative intensity of the two sets of trees in 1933-34 is practically the same as it was in 1930-31, it cannot be claimed that there is any result up to 1934. Here again, unfortunately, there was no crop in 1935; and no blossom records are available to supplement the result shown.

(vii.) EFFECT OF POTASH MANURING.

An account of the results of applying sulphate of potash to half the trees on the Pruning Plot was published (1) in 1928. A light dressing of $2\frac{1}{2}$ cwt. per acre was given to the North half of the plot early in 1923; from March 1925 onwards the same portion received 4 cwt. per acre annually until and including 1931; thereafter the annual dressings were reduced to 2 cwt. per acre.

The portion of the plot previously starved of potash received a dressing of 4 cwt. per acre in April 1928. During 1929 and 1930 it was again starved; in January 1931 it received 4 cwt. per acre and from January 1932 onwards 2 cwt. per acre annually. In addition, occasional light or moderate dressings of nitrogenous or phosphatic manures have been given to the whole plot.

* Fruit buds counted in March 1936 show the same tendency. Though both intensities are reduced owing to crop failure in 1935, the "off-year-pruned" trees ("I" = .15) are much more regular than the "on-year-pruned" ("I" = .42).

In such a history, there are enough changes in treatment to provide good evidence of any effects of potash on the behaviour of the trees. But it does not necessarily follow that any influence the potash may have had must be uniform on all varieties, or even, perhaps, on all pruning treatments. Different varieties show markedly different needs for potash; though all, when growing in a potash deficient soil, may show some benefit from potash, some will show it much more strikingly than others. It was shown in the report referred to, also, that two varieties, Cox's Orange and Allington, had apparently responded to potash treatment in different degrees according to their pruning treatment; the leader-tipped trees showing a clear benefit from potash, whilst the untipped trees did not.

Hence it was deemed advisable to examine the possible effects of potash on each of the twenty sets of trees separately; and to separate in each case the leader-tipped and the untipped trees. In the majority of cases the result is inconclusive; but in some few there seems considerable evidence that the intensity, at least, of the biennial habit has been influenced by the potash.

Fig. 5(*a*, *b*, *c* and *d*) well illustrates the difficulty of interpreting the results. All the curves begin one year after the first light dressing of potash in 1923. In all four cases the curve for potash begins above that for no potash, suggesting that the immediate effect of this first dressing on cropping was unsettling, and increased biennial intensity. In the case of Rival, both tipped and untipped, the potash manured trees soon showed a relative reduction in intensity. Subsequently to 1928, when the potash starved plot received its first dressing (not repeated till 1931), this history is exactly reversed. The *immediate* effect of the one dressing in 1928 was apparently to unsettle cropping and increase biennial intensity. Subsequently repeated dressings greatly reduced the intensity; statistical examination of the records by a method described below* shows that the larger differences are here highly significant. The fact that both pairs of curves separate so widely in the later period, when both sets of trees received potash, is curious. Two attempts at explanation may be hazarded; neither is really satisfactory. Since, by 1931, the potash manured plot had received more than 30 cwt. of sulphate of potash per acre, it seems at least possible that the very sharp rise in intensity may be due to "over-potashing". Varieties certainly differ in their need for potash; it has been believed by some for a

* These intensity figures can be analysed statistically in the ordinary way, using the method of the analysis of variance.

In the case of Rival, firstly trees with potash ("I" = .508) were found to give significantly higher intensities over the whole period than the "no potash" trees ("I" = .401); while pruning treatments did not in any way modify the result.

Considering changes in intensity, apart from a general trend, common to all trees, the "potash" and "no potash" trees behaved quite differently, and there is evidence that the latter did not respond alike to pruning.

In Fig. 5(*a*) and (*b*), each point on the graph is the mean of eight trees and has a standard error of .079. Thus differences of about .29 are significant.

number of years that "over-potashing" of certain varieties is possible. Rival may be one such variety.

It is possible also to regard the potash manured trees as normal for the variety, and the formerly starved trees as still abnormal. Where tree roots travel as deeply as they are known to do in the East Malling soil, potash applied to the surface is at best slow acting. It may be that even the 14 cwt. per acre applied to this section up to January 1934 had not produced its full

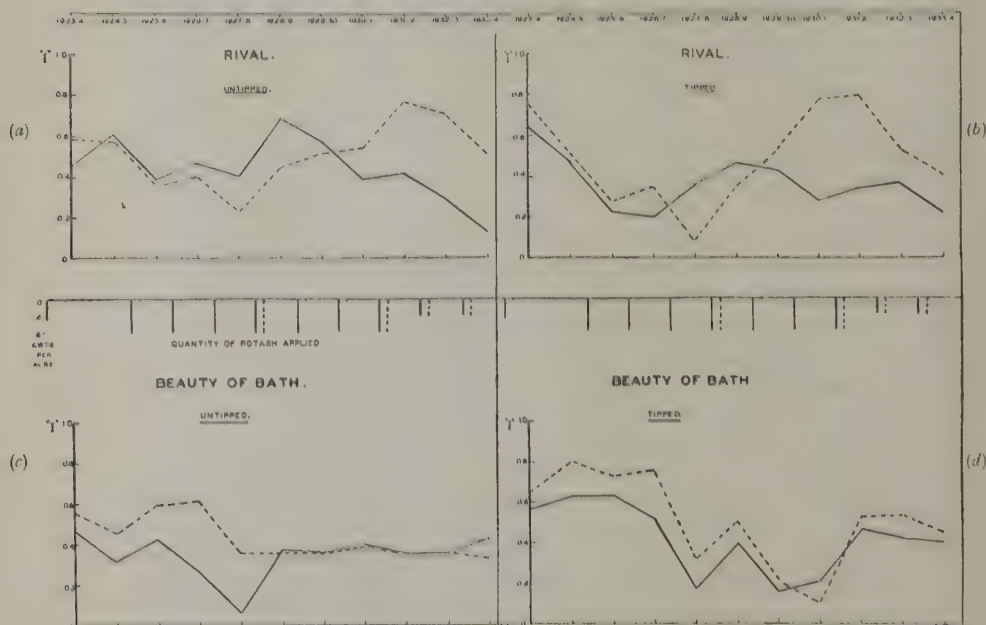


FIG. 5.

Biennial Intensity—Effects of Potash Manuring.

(a) Rival untipped.

(b) Rival tipped.

(c) Beauty of Bath untipped.

(d) Beauty of Bath tipped.

Dotted lines = Potash.

Continuous lines = No Potash.

effect on the trees by the time that year's crop was harvested. This would controvert the view suggested above, since the eventual effect of the potash must in this case be to unsettle cropping and raise the intensity. To the writers the former view seems the more tenable.

In the case of Beauty of Bath, as long as the different treatment of the "potash" and "no potash" plots was maintained, the potash fed trees,

both tipped and untipped, showed a higher biennial intensity than the potash starved trees. Subsequently, the difference between them became small, with some tendency for the formerly potash starved trees to show a relatively higher intensity. The fact that the curves remain very close together is probably in part due to the sod mulch culture of this section of the plot from 1930 onwards. This is referred to below. The grass would necessarily greatly reduce any effect of the potash. It is clear at least that the two varieties have behaved in this respect very differently, and that the leader-tipped trees have in each case behaved similarly to the untipped trees of the same variety. Each type of behaviour can be paralleled from amongst the remaining eighteen sets of trees. James Grieve on commercial "paradise" stocks (mostly No. V) for example, has behaved similarly to Rival: whilst Norfolk Beauty has behaved similarly to Beauty of Bath. Neither of these is on the section grassed down in 1930.

Out of 40 possible comparisons, there is a strong suggestion that potash eventually reduced biennial intensity in 6 cases, and an equally strong suggestion of increase in 5. The remainder are more doubtful; but only 10 cases out of the 40 show a definite conflict of evidence at different portions of their history.

(viii.) EFFECT OF GRASSING-DOWN.

The part of the plot grassed down in April 1930 contained eight sets of trees of six varieties. None of the varieties was duplicated on the continuously cultivated portion of the plot: the effect of the grass can therefore be judged only by comparing the behaviour of the same trees before and after grassing-down.

In 1930 the effect of the grass on the trees was negligible. But in 1931 and 1932 in the absence of liberal feeding with nitrogen (a light dressing of nitro-chalk given in March 1932 had no obvious mitigating effect in that year), the trees all suffered severely: their foliage was yellow, they made little growth, and their crops were much reduced and the fruit small. In 1933 two dressings of nitro-chalk, each of $2\frac{1}{2}$ cwt. per acre, were given in March and May; this was repeated in 1934, each amount being increased to $3\frac{1}{2}$ cwt. per acre. Most of the trees quickly showed an improvement in colour of foliage, growth, crop and fruit size.

Only one set of trees, those of Newton Wonder, shows clearly an effect of the culture method on its regularity of bearing and biennial intensity. The behaviour of these trees is shown in Fig. 6.

All the trees were definitely biennial, with a "B" figure of 100 per cent. or little less, at least from 1920 onwards. Their biennial intensity had been high, and had fluctuated less than that of most varieties. All but three were "in step", bearing their heavy crops in the even years, 1926, 1928 and 1930.

The "out of step" trees were as definitely biennial as the remainder, but showed a slightly lower intensity. They are here included.

The crop of 1929 was slightly heavier than previous "off" year crops. In 1930 the great majority of the trees produced the heaviest crop they have ever had; the effect of the grass had not then become apparent. The "off" year crop of 1931 was very poor, less than one third in number of that of the previous "off" year, 1929; even the three "out of step" trees were much lower, though less proportionately reduced than the remainder. This is reflected in a sharp rise in intensity in 1930-31. The crop of 1932, compared with that of the previous "on" year, 1930, was immensely reduced; it was even considerably less than that of the "off" year, 1929. In effect, the trees had had two "off" years in succession; but since one was so much more nearly complete than the other, the fall in intensity was not very steep.

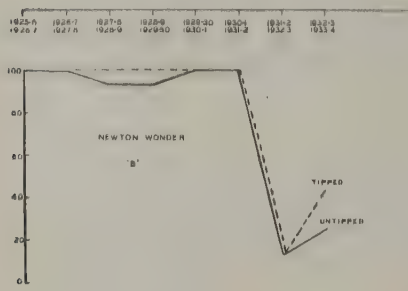


FIG. 6(a). "B."

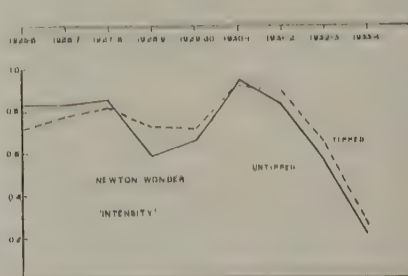


FIG. 6(b). Intensity.

Effects of Grassing-Down and Subsequent Feeding with Nitro-chalk.

NOTE: The graph for "B" is prepared by calculating the percentage of unlike pairs of signs for each unit of trees for each period separately. Thus the lowest point reached by either curve shows that about 12 per cent. of the untipped trees produced either less fruit in 1932 than 1931, followed by more in 1933 than 1932, or vice versa. In the same period the crop of the remaining 88 per cent. of the trees was either rising steadily or falling steadily.

The light dressings of nitro-chalk given in 1932, and the increased dressings in 1933 began to show their effect with the crop of 1933; the effect was still further heightened by the heavier dressings of 1934. Each year there was a considerable increase in total crop.* The great majority of the trees, in short,

* A word as to the economic aspect of the result may be of use to many readers. Though, by means of grassing-down and feeding with nitro-chalk, Newton Wonder was almost completely converted from a biennial to a regular cropping variety, having borne increasing crops for three years in succession, it must be emphasized that the crops of 1933 and 1934 together were but little heavier than those of 1929 and 1930 together, and almost certainly less in proportion to tree size. The fruit, however, was considerably larger in 1933 and 1934, clearly because the two crops were more nearly equal; in neither year was there a breakdown crop, with the very small fruit which that involves. It is clear that the crops of 1933 and 1934 together, given similar market conditions,

were no longer biennial : the effect is seen in the very steep fall in both " B " and intensity.

Whilst the absence of untreated trees is unfortunate, the change in the behaviour of the treated trees in 1933 and 1934 is so very striking that it is hardly possible to doubt the validity of the explanation here given.

(ix.) GENERAL DISCUSSION. CAUSES OF FLUCTUATION IN INTENSITY, ETC.

Certain treatments applied to the trees in the Pruning Plot have, then, clearly influenced either their regularity of bearing or their biennial intensity ; the influence is, as a rule, distinct only where the treatment of certain units has been changed.

One aspect of the results remains to be mentioned—the significance of the wide fluctuations in both " B " and intensity, and the fact that different sets of trees of the same variety tend to fluctuate in the same way.

The graphs already discussed, and the additional graphs in Fig. 7, will serve to illustrate the point. The fluctuations are often very large, even where the treatment has been as uniform over a long period as it is possible to make it. It will be observed that, whilst the curves for different sets of trees of the same variety are in all cases very similar, except where the treatment of one set has been changed, those for different varieties are often very different. The maxima and minima of intensity invariably occur at the same time, so long as one considers trees of the same variety ; for another variety they may be the same, but they are much more likely to be different. Many more examples might be given ; and each set of trees could be grouped in various ways, according to the treatment. The result is always the same.

The inference is obvious. Whatever may be the causes of these fluctuations, they tend at any one time to act on different sets of trees of the same variety in the same way, and *on different varieties differently*.

It is certain that more than one cause is responsible. It has been shown that, in the case of Newton Wonder, the largest fluctuations were caused by a change to sod mulch culture, with subsequent nitrogen feeding. But in most cases the causes are quite distinct from any of the treatments to which the trees were intentionally subjected. It is at least possible that unintentional or unrecorded changes in treatment, as for instance in the time and number of

would have been more valuable than those of 1929 and 1930 together ; but it is impossible to say certainly that had clean culture been continued, they would not have been still more valuable.

It must be pointed out also that another very biennial variety, Allington, which was also under the same sod mulch culture, with nitro-chalk dressings, behaved very differently from Newton Wonder, and showed little or no sign of being converted to regular cropping. It is at least interesting to note that of late years commercial growers have come to regard Newton Wonder as requiring abundant nitrogen, and Allington as being more satisfactory with very much less.

cultivations given during spring and summer, may have some part in them. But the major part must almost certainly be ascribed to uncontrolled factors, of which the most obvious are undoubtedly meteorological.

Whilst much remains to be learnt about the factors favouring blossom setting, it is well known that seasons differ very much in this respect, and that conditions often vary widely from day to day. Where a tree is not so intensely biennial that it produces hardly any blossom in its "off" year,

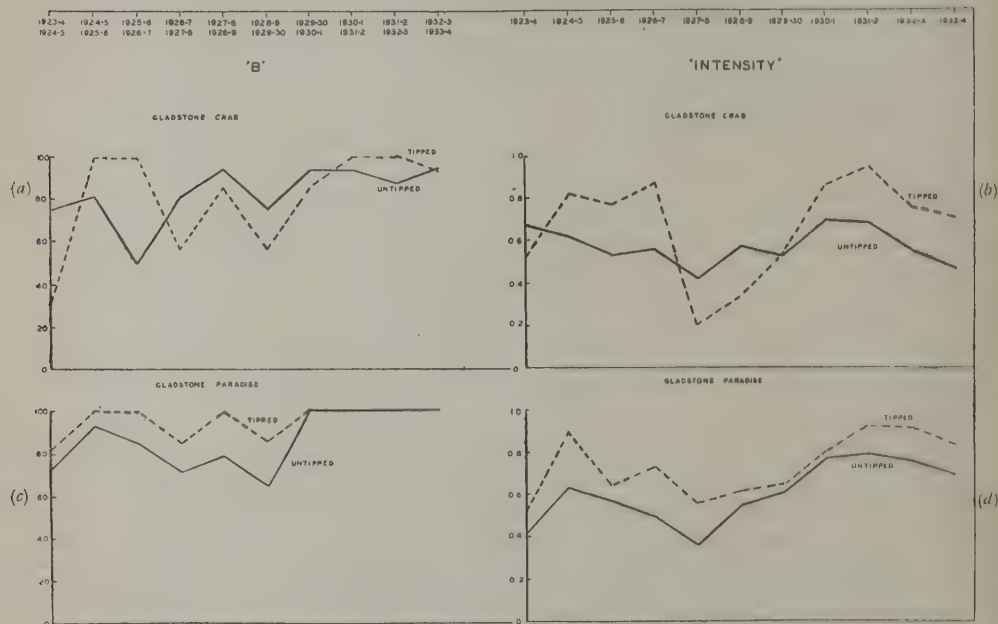


FIG. 7.

Similar Fluctuations in "B" and Intensity of Leader-Tipped and Untipped Trees.

- (a) Gladstone on "Crab", "B".
- (b) Gladstone on "Crab" Intensity.
- (c) Gladstone on "Paradise", "B".
- (d) Gladstone on "Paradise" Intensity.

These graphs for "B" are prepared in the same way as that in Fig. 6 (a).

conditions which favour blossom setting in the "off" year (and similarly those which hinder blossom setting in the "on" year) will reduce biennial intensity and vice versa. The fact that varieties are differently affected in the same season may be at least partly accounted for by differences in time and duration of their blossoming period; and partly, perhaps, by differences in their nutritional requirements.

But blossom setting is itself only one of the factors involved. It has been shown that in certain cases the biennial intensity indicated by number of fruit buds may be higher than that indicated by fruits; and it sometimes fluctuates to at least an equal extent. In such cases factors influencing differentiation must be mainly responsible.

PART IIA. INFLUENCE OF ROOTSTOCK.

The apple rootstock trials at the Station, some of which have now completed seventeen seasons, provide an opportunity for studying the effect of different rootstocks upon the degree to which several varieties show the biennial habit. In Part I of this paper the behaviour of Lane's Prince Albert on three rootstocks has been described. Even here, with a variety which is not markedly biennial, there were distinct differences in its performance on the three stocks. During the six years 1929 to 1934 the variety Bramley's Seedling was for the most part regularly biennial with a high intensity in the last four years, and it is of interest to examine the crop records to see how far rootstock has modified its behaviour in this respect. Table III shows "B" and the intensity for trees on six different rootstocks.

These trees, eight on each rootstock, are taken from the Bramley's Seedling Rootstock Trial on Plot 13, and were sixteen years old at the end of 1934. Originally they were interplanted with Worcester Pearmain at 15 feet square, but the latter variety was removed at the end of 1932. In the spring, 1932, the land was grassed down, and from then on half the trees received nitro-chalk at the rate of 5 cwt. to the acre, and the others had no nitrogen. While the trees on the different rootstocks show very big differences in vigour and actual cropping, as recently described by Hatton (2), and the effects of the cultural treatments were clearly shown (3), the habit of the variety tended to outweigh everything else in respect to biennial bearing. Three sets of eight had "B" = 100 over the whole period. For the other three sets "B" was slightly lower on the whole, but this was found to be due entirely to irregularities in the first two years—after which the habit was as definitely established as in the others. The chief interest therefore lies in a comparison of the intensities, and here significant differences between rootstocks are clearly shown. In the present instance the value of "B" is high enough to rely on a comparison of the three consecutive pairs of years, 1929-30, 1931-32, 1933-34, ignoring the intermediates, whose values do not affect the relative results. This is of course only possible where all values of "B" are high and consecutive pairs of years behave much alike.

The rootstocks evidently divide themselves into two groups, Nos. VII, IV and XII fluctuating less intensely than Nos. I, XVI and II throughout the

period. The difference necessary for statistical significance between averages for the whole period is found to be $\cdot 12$, so that, though between Nos. XII and I the difference is not very definite, the groups are clearly distinct.

The reasons for this somewhat incongruous grouping are difficult to find, especially as blossom records are unfortunately not available. Nos. IV and VII belong to a group of rootstocks which combine early vigour and subsequent heavy crops; but the fact that the very vigorous trees on No. XII have not

TABLE III.
Influence of Rootstock on Biennial Bearing.
Bramley's Seedling.
Number of Fruits, 1929-34.

Stock No.	"B."	Intensity.			Mean.
		1929-30.	1931-32.	1933-34.	
I.	100	$\cdot 23$	$\cdot 71$	$\cdot 77$	$\cdot 57$
II.	100	$\cdot 38$	$\cdot 83$	$\cdot 77$	$\cdot 67$
IV.	87	$\cdot 14$	$\cdot 56$	$\cdot 62$	$\cdot 43$
VII.	81	$\cdot 15$	$\cdot 47$	$\cdot 53$	$\cdot 38$
XII.	87	$\cdot 18$	$\cdot 55$	$\cdot 63$	$\cdot 45$
XVI.	100	$\cdot 27$	$\cdot 81$	$\cdot 88$	$\cdot 65$

yet cropped to capacity may be responsible for their low intensity figure. No. IX is not included, as the majority of the trees are now scion rooted; the one tree which is still reputed to be upon No. IX roots shows a considerably lower intensity than the remainder. At present there is no evidence to show that the cultural treatments have had any effect on the habit one way or the other.

The period is of course too short to draw definite conclusions from, but it seems possible that time may show rootstock to be one of the factors which control the biennial habit—though probably to a minor degree.

PART III.

PRELIMINARY ATTEMPTS TO CONTROL BIENNIAL BEARING.

It is thought worth while to give some account of preliminary experiments made with a view to ascertaining whether the biennial habit of a tree can be influenced by mechanical means, because, whilst it is not claimed that as a result definite conclusions can be drawn, owing to the limited material on which the experiments were carried out, yet it is thought that they have afforded

interesting indications and are worthy of being placed on record for this reason, and also as a possible source of help in future investigations. It is rather a question of stating what has happened as a result of applying certain treatments, and commenting on possible causes, but leaving further experiments to confirm or otherwise the somewhat tentative deductions drawn.

In these experiments two methods of approach only have been used, viz. by means of:

- (A) Blossom removal,
- (B) Fruit thinning,

and it is proposed to deal with the matter under these two headings.

(A) BLOSSOM REMOVAL EXPERIMENTS.

In these experiments no attempt was made to cover other than a limited field; all that was done was to try to ascertain what effect, if any, could be obtained by removing a part or all of the blossoms from a tree. Four treatments in all were applied:

- (1) *Early Stripping*, where the whole of the blossom was removed in the pink bud stage. (Note: In all cases of stripping and thinning the leaves were left intact, the blossom only being removed.)
- (2) *Late Stripping*, where the whole of the blossom was removed when it was dropping.
- (3) *Thinning*, where clusters were reduced to two blossoms, the centre blossom and those attacked by weevil being removed for preference. This was done at the same stage as late stripping.
- (4) *Untreated*, where the blossom was left untouched.

Whole trees were treated by these methods, and, in addition, in order to obtain an indication as to whether similar results might be expected if individual branches instead of the whole tree were treated, the treatments were also applied to different branches on the same tree. Different varieties were also used, to see if there were indications of varietal idiosyncrasies.

Results have been measured mainly by fruiting, as the fruit records are in all cases more complete than those for blossom, there being no records for the latter prior to the experiment starting. It can be generally stated, however, that in these experiments the curves of blossoming and fruiting have usually followed much the same course.

The experiments were commenced in either 1930 or 1931, trees being invariably in their "on" year at the time. Records are available for the

following three or four years. To facilitate reference, trees have been numbered consecutively—see Table IV.

Treatments Applied to Whole Trees (see Table IV, trees 1 to 6 and Fig. 8).

In the case of whole tree treatments, where early stripping and thinning of the blossom were applied to the variety Early Victoria, a known pronounced biennial bearer, uniform results were obtained. Early stripping had the effect of completely changing over the year of cropping and at the same time increasing the biennial intensity. Thinning, on the other hand, appeared to have no measurable effect, one tree which was definitely biennial before thinning

TABLE IV.
Experiments to Control Biennial Bearing.
List of Trees.

Tree No.	Variety.	Stock.	Age from bud. Years.	Treatment.	% Blossom removed at stripping.
1.	Early Victoria	Malling No. XI	8	Untreated	Nil.
2.	" "	" "	8	Untreated	Nil.
3.	" "	" "	8	Stripped early	100
4.	" "	" "	8	Stripped early	100
5.	" "	" "	8	Thinned	—
6.	" "	" "	8	Thinned	—
7.	" "	" "	8	Part stripped early, part untreated	46
8.	" "	" "	8	Stripped and untreated branches roughly alternating	53
9.	" "	" "	8	One side of tree stripped early	61
10.	" "	" "	8	and one side untreated	55
11.	" "	Com. Crab	18	Part stripped early, part stripped late, and part untreated	49
12.	" "	" "	18		61
13.	Lord Derby	Com. Paradise	18		64
14.	" "	" "	18		53
15.	Gladstone	Com. Crab	18		67
16.	Newton	Com. Paradise	19		33*
	Wonder	" "			
17.	" "	" "	19	Part stripped early, part thinned and part untreated	34*
18.	Annie	" "			
	Elizabeth	" "	17		35*
19.	" "	" "	17		31*

* Also a certain amount removed in the process of thinning, but it is doubtful whether this had any effect, for the removal of the blossom did not prevent the setting of a crop.

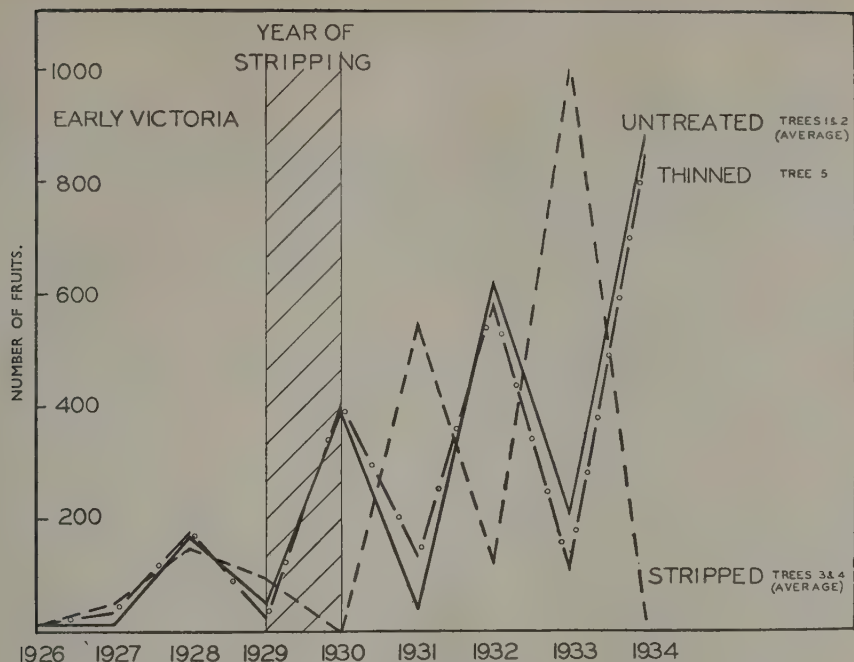


FIG. 8(a).

Cropping of stripped, thinned, and untreated trees of similar previous behaviour.

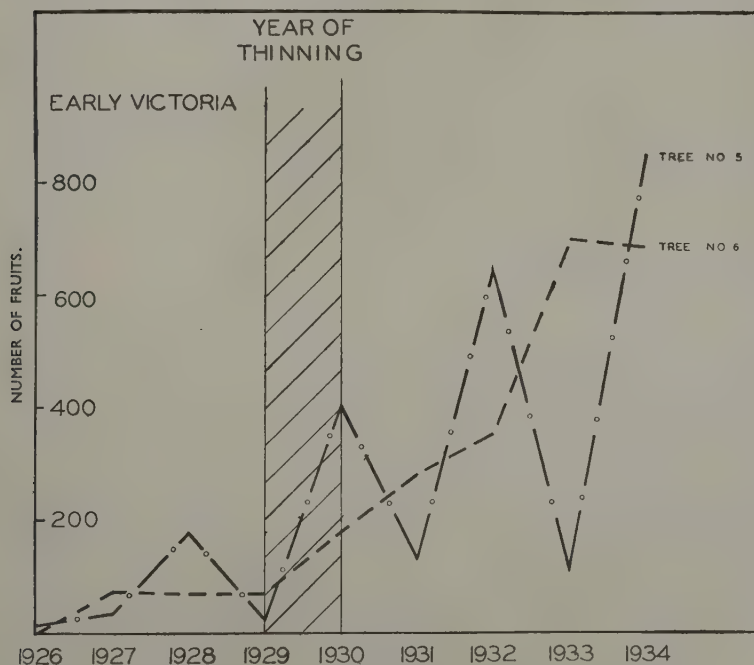


FIG. 8(b).

Cropping of two thinned trees of different previous behaviour.

remaining definitely biennial afterwards, whilst the other, which was in regular bearing, continued so.

The trees in this series were on the whole reasonably comparable ; all with the exception of one of the thinned trees (No. 6) had been definitely biennial from the time of coming into cropping, and were "in step".

The course of the experiment can be clearly followed from the graphs.

Treatments Applied to Parts of Trees.

Experiments on individual branches covered a wider field, early and late stripping and thinning being applied to several varieties (Table IV, trees 7 to 19).

(1) Early and Late Stripping.

In no case was there any apparent difference in the effect of these two treatments where tried one against another, and they will therefore be considered together.

In the cases of Early Victoria (6 trees) and Gladstone (1 tree), the year of cropping of the stripped portions was definitely changed—this is well illustrated in Fig. 9. With Lord Derby (2 trees) and Annie Elizabeth (2 trees), although the stripped portions bore a higher crop than the untreated in the following year, this increase was not sufficient to change their biennial rhythm. With Newton Wonder (2 trees) there was little or no effect.

Whilst at first sight these results might appear to be contradictory and possibly solely due to varietal differences, a closer examination of the figures would seem to show that there are other possible explanations, and that the behaviour of the trees is more nearly alike than would appear on the surface. As will be explained below, there seems to be some ground for thinking that the behaviour of the different portions of a tree have a definite effect on one another, and further, that their behaviour is also affected by the proportion of blossom removed from the whole tree.

(2) Thinning.

In the two instances where this was tried—on Newton Wonder (2 trees) and Annie Elizabeth (2 trees)—there was no apparent effect, the thinned portions behaving in the same way as the untreated portions.

(3) Influence of one branch upon another.

In the cases of the two Early Victoria trees (Nos. 7 and 8) where a direct comparison is possible with wholly untreated trees (Nos. 1 and 2), the previous behaviour of all four having been very similar, the untreated individual branches behaved quite differently from the wholly untreated trees (Fig. 9),

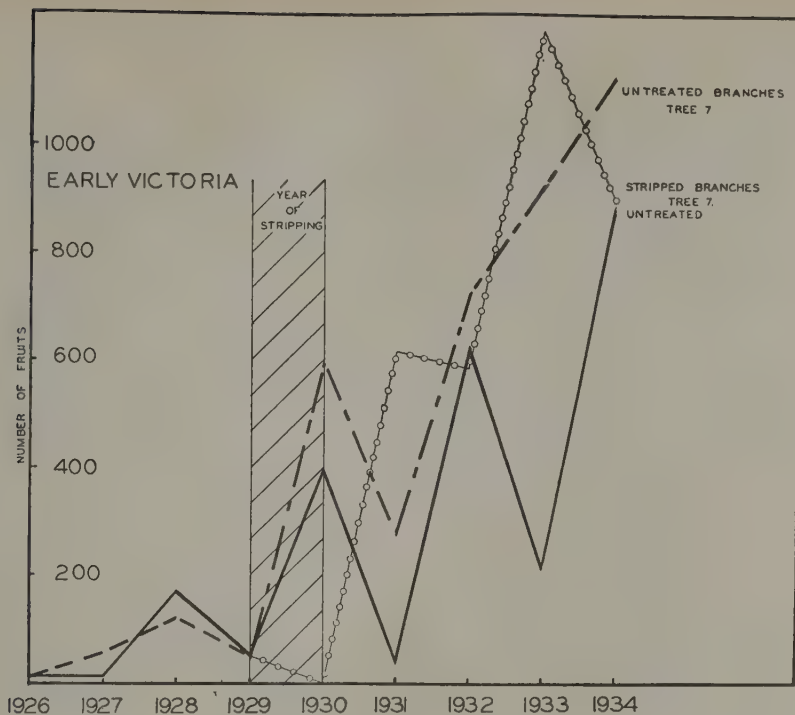


FIG. 9(a).

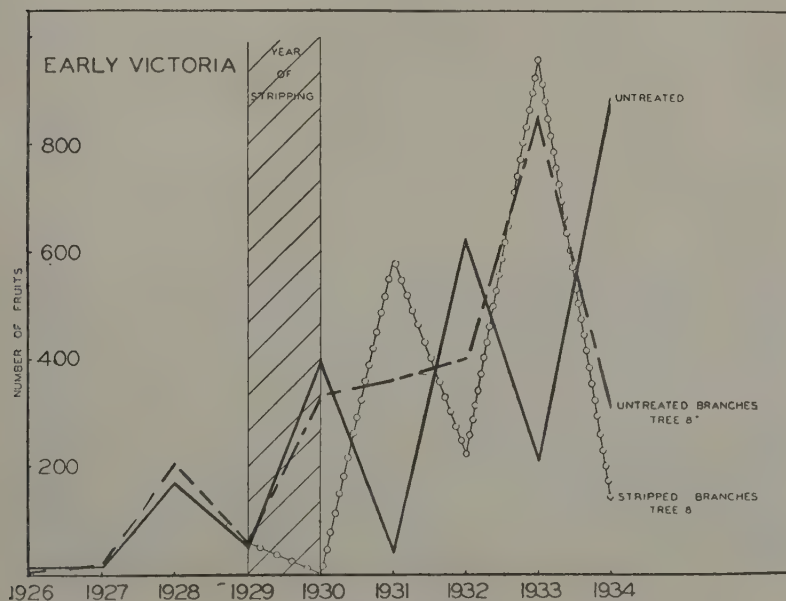


FIG. 9(b).

Cropping of trees having alternate branches stripped, compared with mean of two untreated trees.

NOTE: Since the untreated branches and stripped branches each represent approximately half the tree the figures subsequent to treatment are doubled for easier comparison.

which in itself gives some ground for believing that the stripping of certain branches may have affected the behaviour of the remainder. In the other cases (Trees 9 to 19), as there were no wholly untreated trees with which to compare them, there is no such direct evidence. Indirect evidence, however, would tend to confirm this supposition.

First, in all trees the differently treated portions have either fallen into the same rhythm of cropping or have tended to become less unlike in their behaviour.

Secondly, an examination of the records would seem to indicate that, while variety plays a part, the subsequent behaviour of both treated and untreated branches is associated with the proportion of blossom removed at stripping—the

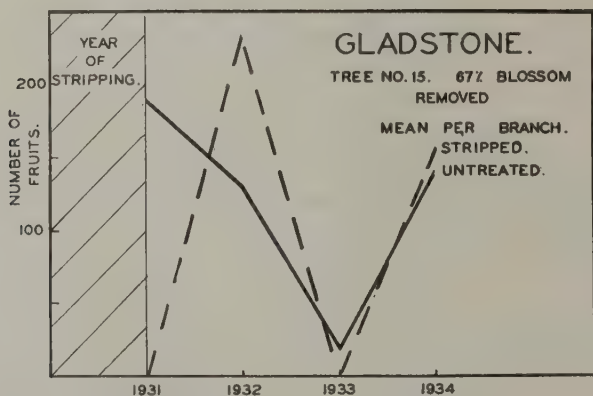


FIG. 10.

NOTE: Tree definitely biennial since 1923, cropping heavily in odd years, 1927, 1929 and 1931.

higher the proportion of blossom removed, the higher would seem to be the amount of blossom and fruit on both treated and untreated portions the following year, the subsequent behaviour of the tree depending on the amount of that blossom and fruit. Thus with Gladstone, where 67 per cent. of the blossom was removed, both treated and untreated portions of the tree blossomed and cropped freely the following year, all portions as a result having little or nothing the next, and a crop again the following year (see Fig. 10); in other words, the year of cropping of the whole tree was changed. From two varieties only some 33 per cent. of the blossom was removed; in one case, Newton Wonder, there was practically no effect; whilst in the other, Annie Elizabeth, the effect was slight. Where stripping has had the effect of completely changing over the

year of blossoming and cropping of the stripped portions and put the two differently treated portions of the tree out of step, the subsequent relative behaviour of the treated and untreated parts would seem to have definitely depended on the proportion of blossom removed. For instance, in the case of the two Early Victoria trees, Nos. 11 and 12, the proportion of blossom removed in 1931 was 49 per cent. and 61 per cent. respectively. Where less blossom was removed the biennial intensity of the untreated portions was for three years higher than that of the treated portions (see Fig. 11(a and b)). Where more blossom was removed the result was eventually reversed.

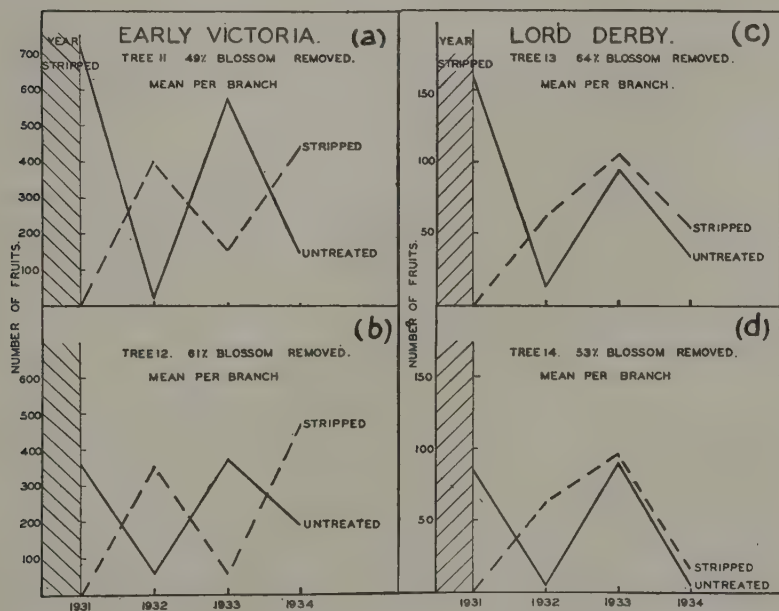


FIG. 11.

NOTE: *Early Victoria*. Trees definitely biennial since 1921, No. 11 more intensely than No. 12, both cropping heavily in 1927, 1929 and 1931.

Lord Derby. Tree 13 definitely biennial from 1927, Tree 14 slightly biennial from 1921 to 1927, then irregular.

Again, with Lord Derby, the same tendency is shown. Here the year of cropping was not changed, suggesting that the influence of the untreated branches predominated. From 1932 to 1934 the biennial intensity of both stripped and untreated portions is, as would be expected, higher where about half the blossom remained on the tree after stripping, than where only one third remained (see Fig. 11(c and d)).

This point is further illustrated by the behaviour of the Early Victoria trees Nos. 9 and 10 (see Fig. 12). Neither of these trees was biennial before 1931. After stripping, the stripped portions became intensely so, the intensity being much higher where only 39 per cent. of the blossom was left than where 45 per cent. was left. This difference may seem small, but it involved leaving on the latter tree somewhat more blossom out of a considerably smaller total than on the former.

The results in the other cases are not inconsistent with this view though they differ in detail.

(B) FRUIT THINNING EXPERIMENTS.

A fruit thinning experiment has been in progress since 1927 on trees of two dessert varieties—Laxton's Superb and Upton Pyne. All the trees are on Malling No. IX stock and were four years old from the bud when the trials started.

There were four treatments in each case:

- (1) *Lightly thinned*, where the fruit was thinned out to approximately three inches apart immediately following the so-called "June drop", i.e. at the end of June or the beginning of July.
- (2) *Heavily thinned*, where the fruit was thinned out to approximately six inches apart at the same time.
- (3) *Stripped*, where the trees were stripped of all their fruit at the same time.
- (4) *Untreated*, where the fruit was left untouched.

Of each variety there are approximately twenty trees heavily thinned, lightly thinned and untreated, and ten stripped.

Graphs are presented for both varieties to show the actual course of fruit bud and fruit production for the different treatments, together with tables as explained above (page 39). In the tables the years 1927 and 1935 have been omitted, as for the former year no fruit bud record is available, and in the latter the crops were destroyed by frost.

With regard to fruiting, to enable a comparison to be made with the stripped trees, it has been necessary to adopt as a standard of measurement for all trees the number of apples on a tree at time of thinning.

Upton Pyne. Between 1929, when the trees started to crop, and 1934 the untreated trees averaged 38 lb. to 6 lb. of fruit per tree per year, the lightly thinned from 32 lb. to 6 lb. and the heavily thinned from 25 lb. to 8 lb. The average percentage of fruits removed at thinning in the "on" years 1929, 1931 and 1933 was approximately 38 per cent. for the lightly thinned and 54 per cent. for the heavily thinned trees, and 53 per cent. and 59 per cent.

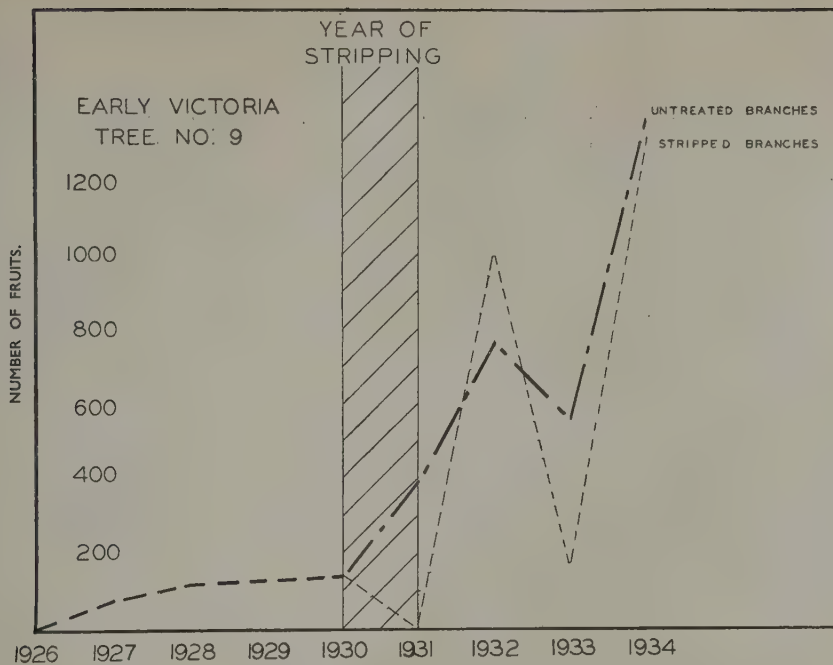


FIG. 12(a).

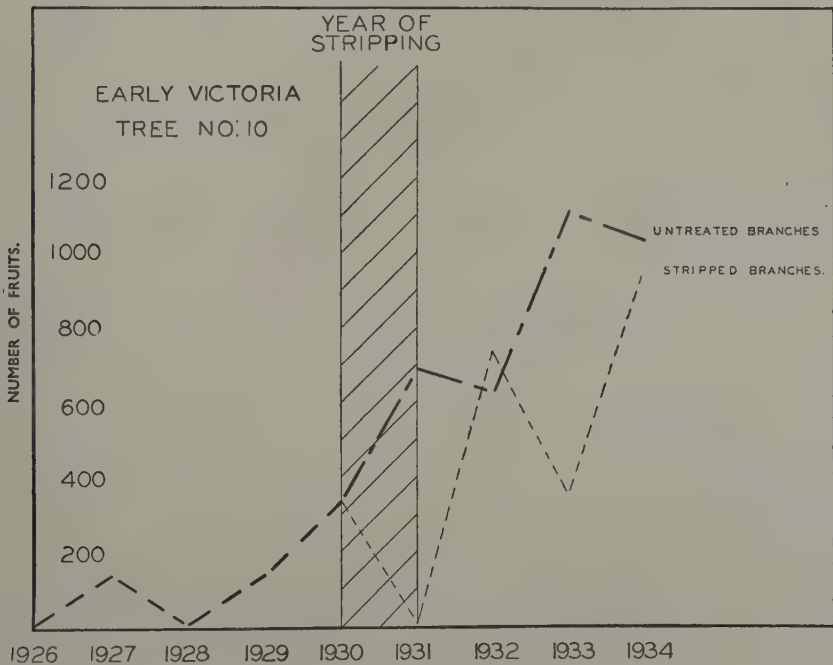


FIG. 12(b).

Cropping of trees where the whole of one side was stripped and the whole of the other left untreated. (See also note on Fig. 9.)

respectively in the "off" years 1930, 1932 and 1934; but the amounts dealt with in the "off" years were, of course, very much less, and the percentage varied very considerably from tree to tree.

For the size of the trees the crops may be said to have been moderately heavy in the "on" years and light in the "off".

There is practically no difference in fruit buds between the untreated and lightly thinned trees either as regards "B" or intensity—they are both high (see Table V). In the case of the heavily thinned there is a very slight reduction in "B", but the intensity is significantly less, while for the stripped trees "B" is below 50 per cent. and the intensity very greatly reduced.

In the case of the fruit (Table VI) the difference is rather more marked. "B" is again high for both untreated and lightly thinned, while the mean of the intensity is also much the same. Though the figures for the lightly thinned are slightly lower than for the untreated, this difference is not significant. The corresponding figures for the heavily thinned are significantly lower than for the lightly thinned, whilst the stripped again are by far the lowest of all.

TABLE V.
Upton Pyne on IX. Number of Fruit Buds after Pruning.

	"B."	Intensity.						Mean Intensity.
		1928-29.	1929-30.	1930-31.	1931-32.	1932-33.	1933-34.	
Untreated	97.0	.97	.77	.89	.62	.70	.84	.807
Lightly Thinned	99.0	.96	.73	.86	.62	.72	.91	.799
Heavily Thinned	92.9	.91	.58	.70	.55	.58	.75	.678
Stripped	44.4	.84	.26	.31	.43	.20	.13	.361

NOTE: Values bracketed together are not significantly different.

TABLE VI.
Upton Pyne on IX. Number of Fruits.

	"B."	Intensity.						Mean Intensity.
		1928-29.	1929-30.	1930-31.	1931-32.	1932-33.	1933-34.	
Untreated	94.0	.99	.65	.72	.38	.47	.75	.660
Lightly Thinned	91.0	.96	.48	.64	.27	.64	.77	.627
Heavily Thinned	75.3	.91	.35	.44	.29	.30	.55	.474
Stripped	37.8	.79	.19	.16	.47	.16	.06	.303

NOTE: Values bracketed together are not significantly different.

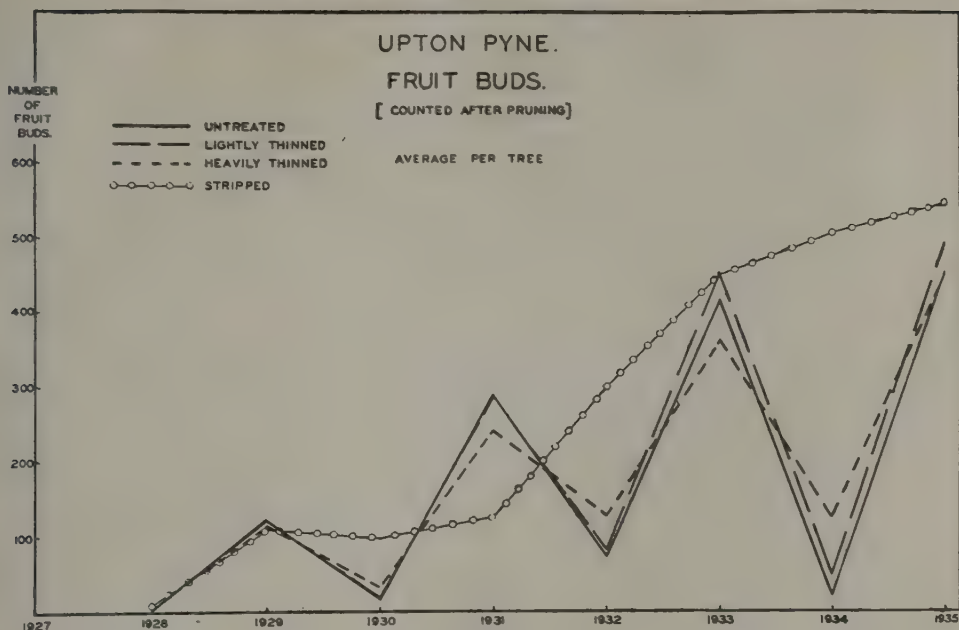


FIG. 13(a).

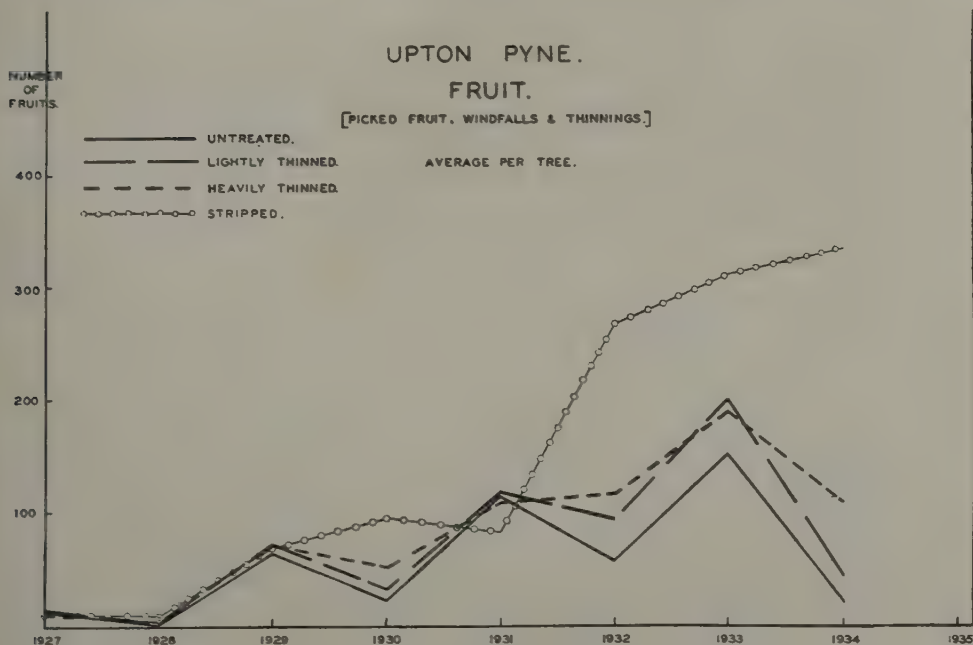


FIG. 13(b).

The biennial tendency of the different treatments is well brought out in Fig. 13. Until 1929 the curves for both fruit buds and fruit are almost identical (the reason for this being that not until that year was there any quantity of fruit to be thinned). Thereafter they begin to diverge, the heavily thinned becoming markedly different from the untreated and lightly thinned, and the stripped very much more so. It is also to be noticed that the fruit bud and fruit curves have followed practically the same rhythm throughout.

Thus it can fairly be claimed that the tendency to biennial bearing has varied conversely with the proportion of fruit removed.

Laxton's Superb. Between 1929 and 1934 (omitting 1930 when the crop was negligible) the untreated trees averaged from 41 lb. to 16 lb. per tree per year and the lightly and heavily thinned from 31 lb. to 14 lb. The average percentage of fruits removed at thinning during these years was 47 per cent. from the lightly thinned and 57 per cent. from the heavily thinned trees.

With the possible exceptions of 1929 and 1933 the crops can only be described as moderate, and were almost certainly smaller for the size of the tree than those of the Upton Pyne.

It will be noticed that, unlike Upton Pyne, fruit buds and fruit have not followed the same rhythm. In fruit buds (Fig. 14(a)) the untreated, lightly thinned and heavily thinned trees have all been biennial, but this has not been the case with the fruit (Fig. 14(b)). In 1931, for some reason, the quantity of fruit that survived until after the June drop was extremely small in relation to the fruit buds for all three treatments, and as a result for three years 1931, 1932 and 1933 there were increasing crops each year. This, of course, has very considerably affected the figures for both "B" and intensity.

In 1931 there was a very large drop of fruitlets between blossom fall and the June drop. It is perhaps interesting to note that this has not markedly affected the biennial rhythm of fruit bud production, though it may have affected the intensity.

TABLE VII.
Laxton's Superb on IX. Number of Fruit Buds after Pruning.

	"B."	Intensity.						Mean Intensity.
		1928-29.	1929-30.	1930-31.	1931-32.	1932-33.	1933-34.	
Untreated	89.5	1.00	.99	.99	.47	.40	.69	.757
Lightly Thinned	93.3	0.98	.96	.98	.39	.40	.63	.723
Heavily Thinned	92.9	1.00	.95	.97	.32	.37	.53	.690
Stripped	50.0	0.99	.29	.36	.17	.09	.12	.337

NOTE: Values bracketed together are not significantly different.

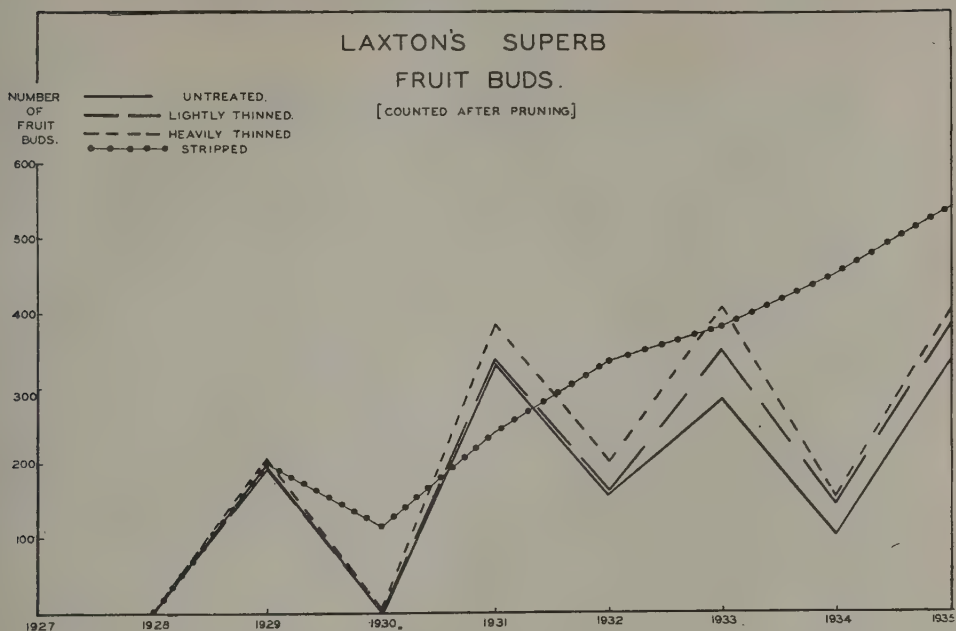


FIG. 14(a).

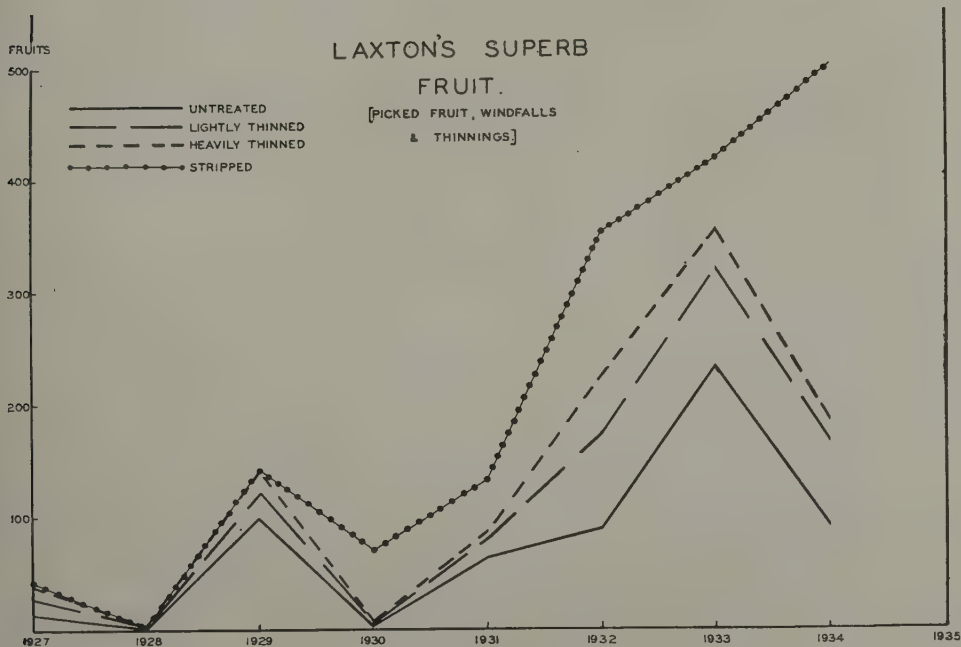


FIG. 14(b).

TABLE VIII.

Laxton's Superb on IX. Number of Fruits.

	" B."	Intensity.						Mean Intensity.
		1928-29.	1929-30.	1930-31.	1931-32.	1932-33.	1933-34.	
Untreated	68.4	1.00	.96	.94	.48	.46	.63	.745
Lightly Thinned	65.7	0.98	.93	.88	.47	.34	.66	.710
Heavily Thinned	60.0	0.99	.88	.84	.48	.29	.57	.675
Stripped	56.0	0.98	.35	.27	.48	.14	.20	.403

NOTE: Values bracketed together are not significantly different.

Neither in fruit buds nor fruit is there any significant difference for " B " or intensity between the untreated, lightly thinned and heavily thinned trees (Tables Nos. VII and VIII). As in the case of the Upton Pyne, both " B " and intensity are very low for the stripped trees compared with the other three treatments.

Discussion. It will be seen that in both these cases the complete removal of fruit each year, even after the June drop, has clearly had the effect of eventually overcoming the biennial habit. The effect of the heavy thinning, though significant in only one instance, is in the same direction in both cases as that of the stripping. Though the difference between the lightly thinned and untreated is not significant in either case, in both it is in the same direction as that of the other two treatments.

SUMMARY.

PART I.

1. An arithmetical method of evaluating the degree to which trees show the biennial habit is described.

2. The trees' history in this respect is shown by two constants. For any particular period, the constant " B " is calculated to show whether the tree is wholly, partially, or not at all biennial; and the violence of its fluctuations is shown by the Intensity (" I "), calculated from the differences between consecutive pairs of years.

3. The importance of fruit bud formation and its relation to fruit set, in any study of regularity of bearing, is stressed.

PART II.

The application of the method described in Part I to the fruit records from the Apple Pruning Plot shows that either "B" or intensity or both may be affected by:

1. The variety. Current ideas of the behaviour of different varieties are in the main confirmed.

2. Root competition from a poplar windbreak.

3. Drastic pruning of formerly "unpruned" trees.

4. A difference in the pruning treatment in the "on" and "off" years. Drastic spur-shortening early in the "off" year reduced biennial intensity compared with similar treatment early in the "on" year.

5. Applications of potash manures. Here results in opposite directions with different varieties were confirmed by changes in treatment.

6. Grassing-down, and subsequently feeding with nitro-chalk. Only one out of six varieties was clearly affected.

The causes of fluctuations in biennial intensity are discussed.

PART III. ATTEMPTS AT CONTROL.

1. Stripping of the blossom from whole trees of Early Victoria completely changed the year of cropping and increased biennial intensity; thinning had no effect.

2. Stripping the blossom of certain branches or parts of trees gave results differing with different varieties. Usually the year of cropping of the stripped parts was changed.

3. Comparison of stripped and untreated branches with whole trees stripped or untreated shows a lower and falling biennial intensity for the former. Differences between partly treated trees could be accounted for by the varying proportion of the whole tree's blossom removed.

4. Results as a whole strongly suggest that differently treated branches of the same tree did not behave independently.

5. No difference was discernible in the results obtained from early and late stripping of the blossom.

6. No result was obtained from blossom thinning.

7. In an experiment carried out on young trees of Upton Pyne and Laxton's Superb, the complete removal of fruit each year clearly overcame the biennial habit. Heavy thinning certainly reduced biennial intensity, but the effect of light thinning, though in the same direction, was not significant.

ACKNOWLEDGMENT.

The writers would like to express their grateful thanks to many members of the East Malling staff, past and present, whose help has made possible the collection and summarizing of the records on which this study is based.

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SOME OBSERVATIONS ON THE INFLUENCE OF
MANURIAL DRESSINGS AND OF CERTAIN
OTHER FACTORS ON THE INCIDENCE OF SCAB
(*Venturia inaequalis* (Cooke) Wint.)
AND OF SPRAY-INJURY IN APPLES

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INTRODUCTORY.

EMPIRICAL observations on Scab have been made incidentally for a number of years at East Malling on the fruit of trees used for pomological research on the influence of rootstock, manuring, etc. The lay-out of the experiments, the ends in view when the treatments were planned and the results achieved along these lines have already been fully dealt with (1, 3), so details in the present paper are unnecessary, and reference to the treatments will be made only briefly and where desirable. It should be borne in mind that the data concerning Scab are merely supplementary to those of a pomological nature. They must therefore be viewed only as a part of the whole; no attempt is made here to recapitulate statements regarding the influence of rootstock, manurial treatment, etc., on growth and cropping, which will be found in the previous papers.

Since the study of disease in relation to deficiency factors appears to be steadily gaining attention, and as the literature shows that comparatively little work has so far been done on Scab in this respect, it will be profitable to set out here the indications already obtained as a prelude to a more intensive study.

The results obtained from one year's observations have already appeared in this Journal (4). They showed that, in the dry season of 1929 (which, nevertheless, proved to be very favourable for Scab-infection in certain districts), established trees of interplanted Bramley's Seedling and Worcester Pearmain, eleven years old and worked respectively on different layered rootstocks, reacted in a very marked degree to the application of balanced manurial dressings (made in 1929 and over a number of years previously (1, page 660)). The earlier dressings were chiefly organic and nitrogenous, to promote growth and establish a strong framework of branches in the young trees. Later, a larger share of phosphates and potash was given, when the trees were established and beginning to crop regularly. During the whole period, the comparable unmanured trees received only "green" manuring to keep the land in

"good heart"—crops of mustard, cabbage or rape were grown amongst the trees and ploughed in.

Grading the fruit for Scab (by the "category" method published elsewhere (4, 6)) showed that, under the seasonal conditions of 1929, the unmanured trees (Plot 14) were much more susceptible to Scab than the similar manured trees (Plot 13). The fungicidal spray-treatment was identical on both plots, lime-sulphur (1-30) being applied at pink-bud and again (1-100) soon after petal-fall.

Evidence was also obtained that the intensity of Scab-attack on the fruit varied with the rootstock (a fact also noted in spraying experiments on Cox's Orange Pippin (4, 5, 7)), and further, that the influence of manuring was shown differentially by trees on different rootstocks.

Since 1929, the crops from the same, and from similar trees under grass, have been Scab-graded, but the difference in results has not once been as pronounced as that initially shown.

RESULTS IN 1930.

Effect of manuring.

Fairly wet conditions prevailed in May, and the spring weather generally was favourable for early infection. June and July were dry on the whole, but many wet periods occurred in August, and secondary infection resulted. Bramley's Seedling and Worcester Pearmain on stock No. V developed late infection on the fruit and leaves to a greater extent than did the same varieties on other rootstocks under observation. This was especially so on the trees on the manured plot (these received a normal dressing of sulphate of potash and a light dressing of sulphate of ammonia in 1930).

Three fungicidal* spray-applications were made, lime-sulphur (1-30) at pink-bud and again (1-100) at petal-fall and about three weeks afterwards. The extra spraying (compared with two sprays only in 1929), by improving control on both plots, undoubtedly had the effect of minimizing any potential differences in degree of Scab-infection as between manured and unmanured trees, and the actual differences are of doubtful significance.

Fruit. The Worcesters, a heavy crop, were harvested in three distinct pickings (representative samples of fruit from each tree at each picking being Scab-graded), which were probably selective for Scab, as some of the apples were to be used in storage tests. The figures in brackets represent the average Scab-equivalent for sixty-four trees (eight on each of eight rootstocks). The

* Certain insecticides, lead arsenate in particular, added to the fungicides mentioned throughout this paper, are not specifically referred to in the text. Although it is admitted that their addition to the fungicides may affect fungicidal action to some small degree, this is not considered of primary importance here, and details, therefore, are not given.

TABLE I.

Apple Scab—Effect of manurial treatment and of rootstock (1930 fruit and leaves).

Scab-equiv.	BRAMLEY'S SEEDLING.				WORCESTER PEARMAIN.			
	Manured (Plot 13).		Unmanured (Plot 14).		Manured (Plot 13).		Unmanured (Plot 14).	
	Fruit. (25)	Leaves. (53)	Fruit. (28)	Leaves. (45)	Fruit. (8)	Leaves. (30)	Fruit. (12)	Leaves. (37)
80		I. II.						
70								IV.
60		V.		VII. III.				
50		VII.		II.				III.
40		III. IV.	VII.			IV.		
30	V. I. VII.			I. IV. V. X.		VII. V.	IV.	VI. I.
20	II. IV. VI.	VI.	II. VI. V. IV.			X. I. II.		II. VII. X.
10	X.	X.	X.	VI.	VII.	VI. III.	III.	V.
0	III.				VI. V. X. I. IV. II. III.		I. VI. VII. II. X. V.	

arbitrary method of computation is merely a ready means of inter-comparing the results of different treatments (4, 6).*

Trees on No. IV and on No. III (very lightly infected when manured) were the most Scab-infected of those unmanured, as in 1929, while, of the manured, those on No. VII and on No. V showed most Scab. The latter are exceptional for, in 1929, manured and unmanured trees on No. V were the most lightly infected. This exception has already been noted: it is thought to be due to seasonal influence, probably allied with manurial treatment.

The Bramley's were all harvested in one picking, and representative samples from each tree were Scab-graded. The difference between the averages for manured and for unmanured trees is not significant, owing to variation in results among the different rootstocks (each such result is an average for eight trees). It is of interest that unmanured Bramley's on No. X, most susceptible of the series in 1929, were the most resistant in 1930. As with Worcester, trees on No. III reacted very favourably to manurial treatment.

Much of the infection on both varieties occurred late in the season, during August.

Leaves. The degree of Scab-infection on the leaves was estimated by Miss B. Carter, then a member of the Research Station pomology staff. After general examination of some of the trees, four Scab categories were chosen, and each tree was then allotted four category figures to represent the infection found at the aspects N. E. S. W. The work was carried out on August 12th and 13th (Bramley's) and on August 19th, 20th and 21st (Worcester). *Figures (in brackets) for fruit and for leaves are not directly comparable in amount for the methods of computing the Scab-equivalents were different.*† Comparison establishes the *relative* positions of the rootstocks, and the *relative* effect of manuring.

There is close similarity between the results of the two independent Scab-estimations where they concern the influence of rootstock, particularly on unmanured trees. The peculiar reaction to manuring of trees on No. III and on No. V, noted above with the fruit, was shown also by the leaves.

Leaves on the East and North were more heavily infected than those on the South and West.

* As a guide to the degree of infection represented by the figures, the following analysis gives an average Scab-equivalent of 25:

Total fruit 121, Scab-free 100, lightly Scabbed 18, moderately Scabbed 3, heavily scabbed 0.
This is not a heavy infection; similarly, a Scab-equivalent of 50 and over would represent a fairly severe attack.

† The four category figures for the leaves of each tree were added, and the sums for eight trees were averaged to give the Scab-equivalent per rootstock.

		E.	N.	S.	W.
BRAMLEY'S	<i>Manured</i>	142	116	97	68
	<i>Unmanured</i>	106	96	88	64
WORCESTER	<i>Manured</i>	75	56	60	42
	<i>Unmanured</i>	93	72	69	58

The numbers are the totals of the category figures for sixty-four trees, regardless of rootstock. The results confirm observations formerly made on a plot of Cox's Orange Pippin (5, p. 281).

To sum up the effect of manuring in 1930, trees on certain rootstocks showed well-marked reactions, but no great differences could be detected in the mass results from manured and from unmanured trees. There was merely a suggestion that unmanured Worcesters were rather more Scab-infected than those manured.

Effect of Pruning.

Some data were obtained from two further series of established Worcester Pearmain and Bramley's Seedling trees (Plot 12), of the same age and on the same range of rootstocks as those on Plots 13 and 14. One series had been pruned* for many years and the other unpruned†; in other respects the two were similar. There were four trees of each variety on each of eight different rootstocks in either treatment.

Again, the Worcesters were harvested in three pickings. The thirty-two pruned trees gave an average Scab-equivalent of 4; those unpruned an average of 12. This direction of difference was consistent for each one of the eight rootstocks. The trees had been carefully examined for the presence of Scab-pustules on the young shoots. None was found on either the pruned or unpruned trees.‡ Better air drainage among the branches, and hence quicker drying of the pruned trees after rain or dew, would render them less liable to infection than the unpruned trees. Other factors, possibly concerning the physiological effect of pruning, may also be concerned. Further, as the trees were planted in two distinct blocks, positional variation may be partly responsible; the unpruned trees were nearer than the pruned ones to the shelter of a railway bank to the South.

* Bramley's were leader-tipped from planting (1920) till 1923, and the laterals were regulated throughout the period till 1930. Branches were thinned out when necessary. Worcesters were leader-tipped and spur-pruned from planting.

† Badly crossing and diseased branches were removed as occasion demanded.

‡ Salmon and Ware (8) have since found Scab-pustules on the blossom bud-scales of Worcester Pearmain in Kent. They may have existed here, but it is not likely that there would be a big difference between pruned and unpruned trees in this respect, by reason of the type of pruning employed.

The Bramley's were harvested in one picking. The thirty-two pruned trees gave an average Scab-equivalent of 8 ; those unpruned an average of 10. This small difference is not significant.

Effect of Grassing-Down.

The trees on Plot 12, referred to under pruning (above), were similar to those on Plots 13 and 14. In the spring of 1930, Plot 12 was sown with grass-seed (sod-mulch system), while the other two remained under cultivation. Plots 12 and 13 each received a light dressing of sulphate of ammonia in July 1930, a normal dressing of sulphate of potash having been given to each earlier in that year. Comparison between the mass average Scab-equivalent (of trees on eight different rootstocks) for Plot 12 and for Plot 13 shows that, with pruned trees (those on Plot 13—and on Plot 14—were regularly winter-pruned), both Worcester and Bramley's showed less Scab on the fruit from grass than from cultivation.

Average Scab-equivalent		PLOT 12 (grassed).	PLOT 13 (cultivated).
{	Worcester	4	8
	Bramley's	8	25

The only difference in treatment was that Plot 12 was dusted with sulphur post-blossom while Plot 13 was sprayed with lime-sulphur (1-100). Pre-blossom fungicidal treatment was the same on both plots (lime-sulphur, 1-30). Subsequent experiments (7) have shown that sulphur-dusting is scarcely as effective against Scab as spraying with lime-sulphur (1-100), so that the difference cannot satisfactorily be explained on that basis. It would appear that grassing-down had some effect in the first year of increasing the resistance of the trees to Scab.

RESULTS IN 1931.

Effect of manuring, of grassing-down and of rootstock.

Weather conditions largely favoured Scab-infection, especially the very wet conditions experienced during the latter half of July, and in August. Secondary (late) infection was of common occurrence.

The series of plots under review, Plots 12, 13 and 14, all received three fungicidal spray-applications, lime-sulphur being used at pink-bud (1-30), at petal-fall (1-100) and about a month afterwards (1-100).

The effect of various manurial dressings was tested on Plot 14 (which thus ceased to be the "unmanured" plot) in an endeavour to renovate some of the trees which, after years of growth without manure, were mainly in a very low state of nutrition. There were four treatments*: (a) nitrogen (N), (b) potash

* For details see (3).

(K), (c) nitrogen with potash (NK) and (d) nil (control). The eight similar unmanured trees on each rootstock (see 1930) were thus divided into four units of two trees each. Guard rows (unmanured) were retained between the manured rows to obviate "robbing".

Sulphate of potash was applied to Plots 12 (grass) and 13 (cultivated), but no nitrogen.

Representative samples of the fruit from each tree were Scab-graded as before.

TABLE II.

Apple Scab—Effect of manurial treatment, of grassing-down and of rootstock (1931 fruit).

Scab-equiv.	BRAMLEY'S SEEDLING.			WORCESTER PEARMAN.		
	Grassed, 1st year (Plot 12). (13)	Cultivated and manured (Plot 13). (17)	Cultivated and "unmanured" (Plot 14). (13)	Grassed, 1st year (Plot 12). (7)	Cultivated and manured (Plot 13). (16)	Cultivated and "unmanured" (Plot 14). (13)
		VII.				
25						
					X.	III.
20	X.	III. VI. IV.			V.	X.
	III.	X.	IV.		VII. II. IV.	VII.
15	II. IV. VII. I.	II. V. I.	VII. III. X. VI. V.		I.	IV.
				III.	VI. III.	I.
10	VI.		I. II.	X.		VI. II. V.
	V.			IV. VI. I. VII.		
5				V. II.		
0						

The figures* in brackets are, again, the average Scab-equivalents for all trees under observation, regardless of rootstock. Those for Bramley's are the average of four trees per rootstock (Plot 12) and eight trees per rootstock (Plots 13 and 14), and for Worcester, of two trees per rootstock (Plot 12), four trees per rootstock (Plot 13) and eight trees per rootstock (Plot 14). They are comparable with those of 1929 and 1930 only relatively and not quantitatively, for the method of computing them was slightly modified in 1931. For the purpose of this paper, all trees on the "unmanured" Plot 14 have been regarded as though no differential manuring were practised in 1931, for it was evident that the treatments had no very marked effect on the incidence of Scab in the first year.

The heavy crop of Bramley's was thinned in July, and the immature fruit then removed was Scab-graded. The separate results from immature and from mature fruit were averaged for Table II.

It will be seen that, as in 1930, the fruit (especially of Worcester) from the grassed plot was again more lightly Scab-infected than that from the manured or "unmanured" plots under cultivation. Trees under grass were now showing well-marked signs of nitrogen-deficiency (yellow foliage and early defoliation), while those under cultivation were not (3). There was also a tendency towards more infection on Plot 13 (manured) than on Plot 14 ("unmanured")—a reversal of previous indications.

The reaction of trees on the different rootstocks recalls previous experience in certain noteworthy instances. With Worcester, No. III again showed a well-marked beneficial effect of manuring, while No. V again reacted in the opposite direction. With Bramley's, No. X ("unmanured") did not repeat its behaviour of 1930, while No. III failed to respond beneficially to manuring, its influence thus differing from that in 1929 and 1930.

That the differential manuring of Plot 14 had little effect on Scab in the first year is shown by comparing the average Scab-equivalents for all trees on that plot (Bramley's 13, Worcester 13) with those for control trees still unmanured (Bramley's 13, Worcester 15). Further, by comparing the degree of susceptibility of trees on the different rootstocks (from least to most Scab) under these two heads, it will be seen that differential manuring has not greatly modified the relative positions in the rootstock series:

Bramley's	{ All trees	II, I, V, VI, III, X, VII, IV.
	{ Unmanured trees	II, I, III, V, VI, X, VII, IV.
Worcester	{ All trees	II, V, VI, I, IV, VII, X, III.
	{ Unmanured trees	VI, II, V, I, X, IV, VII, III.

* 10 represents moderate infection; 30 is very severe.

The average Scab-equivalents for trees on Plot 14 according to manurial treatment and regardless of rootstock were:

	Nil	K	NK	N
Bramley's (average of thinned and matured fruit)	13	15	12	11
„ (matured fruit only)	14	18	12	12
Worcester (matured fruit only)	15	14	10	14

The relatively high figure for Bramley's (matured fruit) receiving K was due almost entirely to trees on No. III and VI respectively, which developed Scab out of all proportion to those on other stocks. A relatively low figure is shown by both Bramley's and Worcester receiving NK.

RESULTS IN 1932.

Effect of manuring, of grassing-down and of rootstock.

Weather conditions were very favourable for early and for late Scab-infection. Cold, wet, sunless days occurred in April and early May; the trees appeared to make little or no progress for some weeks after bud-break and, as pointed out elsewhere (7), two pre-blossom sprays, then an unusual circumstance at East Malling, were necessary for effective Scab-control on certain varieties. A further wet period towards the end of July led to the appearance of secondary infection.

The trees on Plots 12, 13 and 14 received one pre- and two post-blossom applications of lime-sulphur as in 1931. Plot 13 was grassed down in spring, 1932, as Plot 12 had been in 1930, but no manure was given to either plot. The various manurial dressings on Plot 14 were continued as in 1931.

Representative samples of the fruit from each tree of Bramley's and Worcester were Scab-graded at picking-time. The Scab-equivalents were worked out as in 1931, so they are comparable in amount for the two seasons.

There is no longer a direct comparison between cultivation and grass treatment, for Plot 13 is itself under grass. However, the cumulative effect of grassing-down, resulting in reduction of Scab-infection, is well shown by comparing results on Plot 12 (second year under grass) with those on Plot 13 (first year under grass), particularly as regards Worcester. Nevertheless, it must be borne in mind that the trees on Plot 12 were by this time showing symptoms of severe nitrogen-deficiency, and control of Scab by this drastic means would scarcely be economic!

It is not claimed that the data assembled in Table III are susceptible of detailed analysis. The results shown for each stock-scion combination on each plot is an average for only two trees, yet definite tendencies appear which cannot be dismissed as insignificant. For example, nitrogenous manuring on Plot 14 has resulted in an unmistakable rise in Scab-infection (when compared with potash manuring or with no manure), especially on Worcester, whether the nitrogen was applied alone or in combination with potash. This tendency particularly concerned certain rootstocks (notably No. III with Bramley's and No. X with Worcester) and not others, and it has had the effect of extending the range of Scab-equivalents covered. In general, stocks No. I, II, V and VI induced Scab-resistance in both Bramley's and Worcester, whatever the treatment. There was a similar tendency in 1931, with the outstanding exception of Worcester on No. V (manured) already mentioned. No. III, IV, VII and X tended generally to induce relative susceptibility in both varieties. The reaction of Cox's Orange Pippin worked on these rootstocks was, on the whole, different (4, 5, 7). Fluctuations in the relative positions of the rootstocks, apart from the two specially mentioned above, may be due merely to chance—the evidence is scarcely enough to support further deductions.

RESULTS IN 1933.

Effect of manuring and of rootstock.

In the winter of 1932-33, the Worcesters were grubbed from Plot 13 to give the Bramley's there sufficient room to develop freely. Moreover, as the grassing-down of Plot 12 (in spring, 1931) had produced symptoms of severe nitrogen-starvation, an attempt was made in 1933 to bring about recovery by applications of a nitrogenous manure through the grass. The plot was therefore divided into parallel, diagonal strips, one tree wide. Alternate strips received nitro-chalk at the rate of 15 cwt. per acre (a heavy dressing designed to give rapid and clearly-defined results) and 5 cwt. per acre. Bramley trees on this plot acted as guard rows, unmanured.

The Bramley's on Plot 13 had been grassed-down in spring, 1932; the grass had grown poorly, however, the trees were still very vigorous, and symptoms of nitrogen-starvation were not evident. The problem here, therefore, was to keep the trees in a healthy, yet not too vigorous state by the application of the right amount of nitrogen to counteract any excess withdrawal by the grass. Alternate, diagonal strips were given nitro-chalk at 5 cwt. per acre, while the others received no manure as a control.

On both plots, the treatments were so arranged that half the number of trees on each stock received either one or the other treatment. The manures were applied at two periods in spring, half the total dressing at each period.

TABLE IV.
Apple Scab—Effect of manurial treatment and of rootstock (1933 fruit).

Scab-equiv.	BRAMLEY'S SEEDLING.						WORCESTER PEARMAN.					
	Grassed, 2nd year (Plot 13). Nitro-chalk.			Cultivated (Plot 14). 3rd year of treatments.			Grassed, 3rd year (Plot 12). Nitro-chalk.			Cultivated (Plot 14). 3rd year of treatments.		
	NIL. (14)	5 cwt. (16)	NIL. (10)	NK. (14)	N. (13)	K. (11)	5 cwt. (2)	15 cwt. (3)	NIL. (2)	NK. (3)	N. (3)	K. (2)
		V.	X.			X.						
25												
20	IV. V. III. VI. II.	III. II. X.		I. X.	VII.							
15				IV. VI. V. II. III.	III. II.	IV.	3	4	3	7	6	7
		VI. VII. I. IV.	I.					No Scab-equivalent more than :				
10			V. II. VI. VII. IV.		VI. X. V. I.	VI. V. II. III.						
5	VII. X. I.				V.	III. I. VII.						
0			III.	VII.								

The differential manuring of Plot 14 was continued for the third successive year.

The summer was very dry. Fairly wet weather occurred in May, and there was a long blossom period during which Scab developed on control Cox trees in certain spraying trials. The pink-bud application of lime-sulphur, however, was, in general, proof against this on these plots, and little opportunity occurred during the following months for infection to become really well established on Worcester fruits, which were picked at the end of August. Bramley's, being picked nearly a month afterwards, developed much secondary infection of the small-spot type during September, when the weather was abnormally wet. The usual three applications of lime-sulphur were made on Plots 12, 13 and 14 (see 1931 and 1932). Representative samples of the fruit were graded, and the Scab-equivalents worked out as in 1932.

The results given in Table IV are averages for two trees on each rootstock. Bramley's showed a tendency to develop slightly more Scab (nearly all small, late-infection spots) where manured with nitrogen, especially on No. III stock, as in 1932. Trees on No. X were an outstanding exception on Plot 14—Bramley's on this stock have behaved in a very inconsistent manner from year to year. Those on No. VII were very lightly infected when manured with potash, alone, or in combination with nitrogen. Bramley's on No. V on Plot 13 (grassed) were, relatively, more susceptible than usual. Apart from this, little can profitably be deduced from the results on account of the small unit of trees on each stock and the variation of results from tree to tree. Scab did not develop sufficiently on Worcester for any conclusions to be drawn.

RESULTS IN 1934.

Effect of manuring and of rootstock.

The Worcesters on Plot 12 which received 15 cwt. nitro-chalk per acre in 1933 were given no manure in 1934, while those which received 5 cwt. per acre in 1933 were given this dressing again in 1934. On Plot 13, the manurial treatments given to the Bramley's in 1933 were repeated.

Again the summer was very dry. A wet period towards the end of April seemed to encourage infection already started, and resulted in a moderate attack of Scab during the blossom period. Post-blossom spray-treatment, coupled with the dry weather, however, soon checked this, and infection did not become severe on the fruit.

Trees on Plots 12, 13 and 14 were fungicidally sprayed at the usual three periods, pink-bud, petal-fall and three weeks later. Instead of lime-sulphur (1-100) at petal-fall, as formerly, Bordeaux mixture (6-12-100) was used, as it was considered more likely than the weak lime-sulphur to check the infection

TABLE V.
Apple Scab—Effect of manurial treatment and of rootstock (1934 fruit).

Scab- equiv.	BRAMLEY'S SEEDLING.						WORCESTER PEARMAIN.					
	Grassed, 3rd year (Plot 13). Nitro-chalk.			Cultivated (Plot 14). 4th year of treatments.			Grassed, 4th year (Plot 12). Nitro-chalk.			Cultivated (Plot 14). 4th year of treatments.		
	Nil. (13)	5 cwt. (13)	Nil. (15)	Nil. (14)	N. (19)	K. (13)	5 cwt. (2)	Nil. (3)	Nil. (1)	NK. (1)	N. (1)	K. (1)
					I. V.	I.						
20		V.	VII. IV. I.		IV. III.							
					VI. VII.	V. II.						
15												
10												
5												

No Scab-equivalent more than :

1

2

2

2

6

4

already progressing. The use of Bordeaux mixture, however, resulted in the development of severe fruit-russetting on Bramley's Seedling. It is not known whether this was due to interaction on the trees between Bordeaux mixture and the deposit of lime-sulphur (with lead arsenate) from the pink-bud spraying, or to the inclusion with the Bordeaux of sulphite lye (0.75%) as a spreader for nicotine (also included) against Apple Sawfly, or to the heavy application of spray. The Bordeaux was reduced in strength from 8-12-100 (normal "full-strength") to 6-12-100 as a precaution against spray-damage. The combined fungicide-contact-insecticide spray was heavily applied to give the better control of Sawfly.

The fruit was graded and the Scab-equivalents worked out as in the last few years.

The results given in Table V are averages for two trees on each rootstock. As in 1933, Bramley's again showed a tendency to develop slightly more Scab (on Plot 14) when manured with nitrogen, particularly trees on No. III stock. Those on No. VII were, again, relatively lightly infected when manured with potash, alone, or in combination with nitrogen, and those on No. V were relatively heavily infected both on Plot 13 (as in 1933) and on Plot 14 when manured with nitrogen. Much of this infection occurred late in the season, as with this stock in 1930. For the second successive season, there was not enough infection on Worcester to enable any conclusions to be drawn.

Effect of manuring and of rootstock on spray-damage.

The Bramley's on Plot 14 were graded for russetting by a "category" method to determine whether the differential manuring treatments, and the rootstocks on which the trees are worked, had influenced the severity of the russetting already mentioned. Four russet categories were chosen, according to intensity as well as area of the russeted patches. The apples were graded and the russet-equivalents calculated in the same way as for Scab (4, 6). In Fig. 1, the six fruits shown represent the types chosen for grading purposes. Each is a maximum for its category, and each is approximately twice as severely damaged as that next below it in order of russetting. On the top line, the grading is to a standard of *area* russeted; on the bottom line, of *intensity* of russetting. When grading, vertical pairs of fruits were placed in the same category and were thus awarded the same "marks". In addition to the fruits photographed, unblemished apples formed a "clean" grade, and any fruits more severely russeted than those illustrated formed a grade at the other extreme. Many apples were found which bore interesting markings. Two of these are shown in Fig. 2. The spray, applied when the apples were very small (soon after "setting"), spread over that part of the skin facing towards the direction of the spray, and apparently the excess flowed downwards to form suspended

drops. These dried before "run-off" occurred, and at these points the injury was most severe. It will be seen that the tapering streaks all point in approximately the same direction, showing in what position each fruit was held by its stalk when the spraying was done. Subsequently, internal expansion of the fruit during normal growth exerted considerable lateral tension on the dead portions of skin, leaving them ultimately as a series of small "islands" which are clearly visible.

It is a noteworthy sidelight on a widely-held opinion that heavy applications of spray are more likely to lead to spray-damage than lighter ones, although it is not necessarily implied here that the formation of "pools" on leaves and fruits can always be avoided under practical conditions, whether the spraying be heavily done or not.

The classified results are shown in Table VI. Each is an average of two similarly-manured trees on the same rootstock.

TABLE VI.

*Fruit-russetting (spray-damage)—Effect of manurial treatment and of rootstock.
Variety—Bramley's Seedling.*

Rootstock.	Russet-equivalents.				Average for Stock.
	Nil.	NK.	N.	K.	
I.	17.8	13.4	24.3	21.7	19
II.	12.6	11.2	13.9	16.5	14
III.	9.9	15.2	20.8	10.0	14
IV.	19.1	15.2	20.7	11.3	17
V.	12.3	15.5	24.8	17.7	18
VI.	14.6	14.7	18.4	10.0	14
VII.	20.2	10.8	16.8	8.6	14
X.	14.1	13.6	14.9	11.3	14
Average for treatment	15	14	19	13	

The conclusions that can be drawn are, again, limited by the small number of statistical units available. Nevertheless, there is a distinct suggestion that trees manured with nitrogen only for four successive years were more susceptible to this form of spray-damage than those receiving K or NK over a similar period, or those unmanured since 1920. This is true not only of the average for the treatment, regardless of rootstock, but also for nearly every rootstock of which the final average is compounded. Trees on No. I, on No. V and on No. IV showed indications of greater susceptibility than those on other stocks (fourteen, a frequently-recurring average russet-equivalent, can be regarded as the normal). Cox's Orange Pippin on No. V stock gave similar indications in certain spraying trials recorded elsewhere (4, 7). Without more detailed study

of this differential response of rootstock, it cannot be determined whether it is merely an expression of the growth-habit of the tree, or whether it is constitutional and therefore more deep-seated. No. V stock has certain other peculiarities, for trees worked upon it show leaf-scorch (caused by potash deficiency) more than those on other stocks (2); further, it will be recalled that trees on this stock seem specially prone to late Scab-infection when suitable weather conditions occur in late summer.

There was not time to make a survey of spray-damage on the leaves. Moreover, by the time any leaf-damage was visible, an estimation would have been difficult to make with accuracy, for the symptoms were complicated by leaf-scorch due to nutritional deficiencies.

RESULTS IN 1935.

A very severe frost occurred on the night of May 16th-17th. As a result, the crop was almost completely ruined, and no data are available for this season.

DISCUSSION OF RESULTS.

These experiments were not designed with the influence of manurial dressings on the incidence of disease as a major issue, and any results obtained are only incidental to those of a pomological nature.

Possibly the most obvious point to be gained is that, for the influence of manuring on Scab to be best studied, the normal spray-programme for Scab-control should be modified, and the disease should be allowed to develop to an appreciable extent, though not sufficient to prejudice the health of the trees. A series of severe, unchecked outbreaks of Scab year after year on the same experimental trees would, in time, defeat the object of the experiment. Naturally, when the study of disease is not a primary issue, the trees must be kept as free as possible from infection. In that respect the present study has probably been hindered, for potential differences—and there are many pointers that manuring of apples has a profound influence on the incidence of Scab—were nullified by too complete a spray-programme. Again, the dry weather of the past few seasons has favoured the beneficial action of fungicides used against Scab, and results of manurial influence on infection have not freely been forthcoming. During the later years, subdivision of treatments has resulted in a reduction in the number of statistical units from which data could be obtained, thus making apparent differences of doubtful significance in some instances.

In spite of the lack of such definite results as might have been desired from this preliminary survey, some light has been thrown on the possibilities underlying a more searching investigation of the problem from the disease viewpoint. It is at least clear that the relationship between the incidence of Scab and the

manurial treatment given is by no means a simple issue. Governing factors of primary importance are the scion variety, the rootstock and the weather conditions. Although the present observations do not include soil conditions, it is a safe assumption that this factor also is important. These variables seem to exert their separate influences one upon another, so that the ultimate reaction on the tree, and therefore on the disease, is very complex. For instance, these data suggest that, given certain weather conditions, trees worked on No. V rootstock respond differently from similar trees on other stocks to manurial treatment. Again, a variety worked on a particular rootstock may be relatively susceptible when manured and relatively resistant when unmanured (e.g. Bramley's on No. I in 1929 (4)), yet this may not be so under different seasonal conditions.

It seems probable that the same will be true of spray-damage. Present data concern only one season, but they suggest that scion variety and rootstock are governing factors, as with Scab. Moreover, evidence has frequently been forthcoming from general practice that weather conditions influence the incidence of spray-damage.

The above remarks are not intended to suggest that control of Apple Scab can be sought entirely by means of suitable manurial treatment. This can do much, but, as far as present knowledge goes, spraying is still required. It is suggested, however, from the evidence put forward, that spraying for Scab-control depends for its efficacy on the condition of the tree, which, in turn is pre-disposed towards susceptibility or resistance to this disease (and, indeed, to spray-damage) by the kind of manurial treatment given. More knowledge is needed about the effects of that manurial treatment, and this can profitably be the basis of further research.

SUMMARY.

The data are presented and discussed from supplementary observations extending from one to five seasons on the incidence of Apple Scab on Bramley's Seedling and Worcester Pearmain in relation to manurial dressings, grassing-down, pruning and rootstock. Certain results were obtained, during one season, concerning fruit-russeting on Bramley's following the use of Bordeaux mixture.

Routine fungicidal spray-treatment, and, during the last few seasons, the occurrence of weather conditions generally too dry to favour the development of Scab, combined to prevent infection from becoming severe enough for large differences between results of treatments to be shown. The data suggest, however, that the degree to which *Venturia inaequalis* caused infection of the fruit was governed by the manurial treatment of the trees, by grassing-down, by pruning, by seasonal conditions, and by the rootstocks on which the trees are

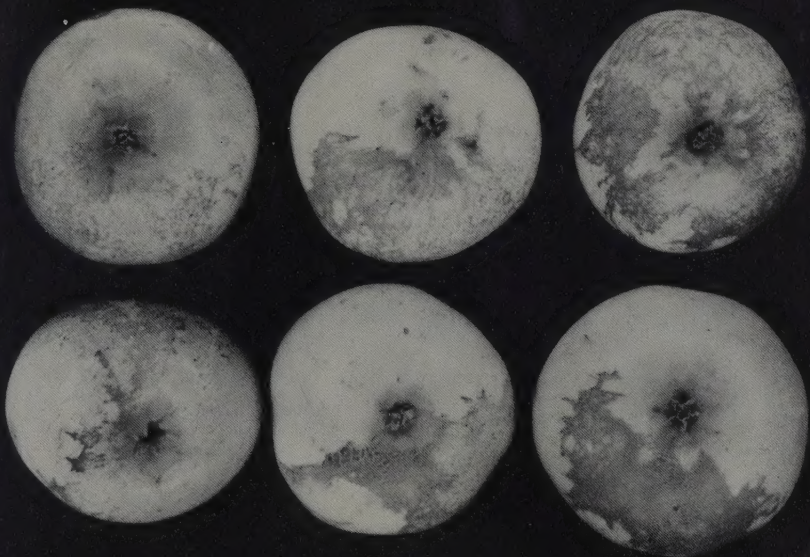


FIG. 1.

Standards of russetting used in grading Bramley's Seedling damaged by Bordeaux mixture.
Top line, for *area* ; bottom line, for *intensity*.

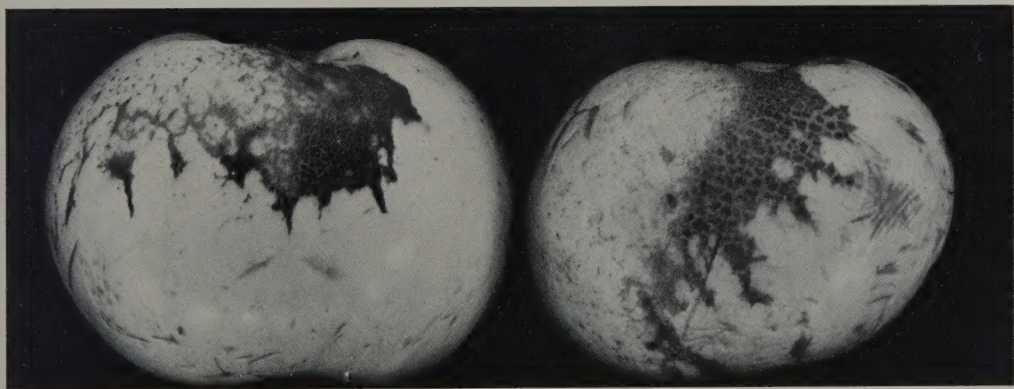


FIG. 2.

Russet-patterns on Bramley's Seedling, found where excess spray-fluid collected.

worked. There were several indications that, in general, nitrogenous manuring increased the tendency to Scab, while grassing-down decreased it. Rootstock influence showed differential reactions to these stimuli, and weather conditions provided a further source of variation in response. The disease on the leaves developed more on the East and North of trees than on the South and West, and was influenced by rootstock and by manurial treatment.

A general survey of the effect of rootstock, regardless of other factors, showed that the fruit of both Bramley's Seedling and Worcester Pearmain was more susceptible to Scab with trees worked on No. III, IV, VII or X than on No. I, II, V or VI. Other experiments (referred to) show that the reaction of Cox's Orange Pippin on these rootstocks was, in general, different.

Fruit-russetting on Bramley's Seedling in 1934, caused by Bordeaux mixture applied at petal-fall, was rather more severe on trees receiving only nitrogen than on those receiving potash, nitrogen with potash, or no manure. Trees on No. I, IV or V stock showed more russetting than those on No. II, III, VI, VII or X.

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BOOK REVIEWS

SCIENTIFIC HORTICULTURE. Vol. IV. 1936. (Price 3s. 6d. (postage 5d. extra). Published by the Horticultural Education Association.)

This volume includes the names and addresses of the 252 members of the Horticultural Education Association: a list of the Horticultural Instructors, county by county, for England, Wales, Scotland and Ireland: the President's address and specialized articles on horticultural subjects by well-known experts. The presentation of the book is excellent, for the paper is good and the type easy to read. The illustrations vary in merit. This is a book that can be strongly recommended to research workers, teachers, growers and even to distributors and students, for it contains material that will be of interest to all interested in horticulture.

H.V.T.

RASPBERRIES AND KINDRED FRUITS. By E. MARKHAM. (Macmillan, London, 1936, pp. 68. 6s.)

This small volume on raspberries, blackberries and logans is well printed and illustrated, but the author does not appear to have noted some of the more recent English work on the subject.

D.A.